STUDY OF DOWNSTREAM EROSION POTENTIAL
Rocky Flats Plant Site

Task 25
of the
Zero-Offsite Water-Discharge Study

Prepared for:

EG&G ROCKY FLATS, INC.
Plant Engineering/
Civil Engineering-
Environmental Restoration
P.O. Box 464
Golden, Colorado 80402-0464

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Prepared by:

ADVANCED SCIENCES, INC.
405 Urban Street, Suite 401
Lakewood, Colorado 80228

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DISCLAIMER

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

STUDY OF DOWNSTREAM EROSION POTENTIAL

EXECUTIVE SUMMARY

This report is the product of one of thirty identified tasks being conducted for, and in the development of a Zero-Offsite Water-Discharge plan for the Rocky Flats Plant (ASI, 1990a). The Plan is being developed in response to Item C.7 of the Agreement in Principle between the Colorado Department of Health (CDH) and the Department of Energy (DOE)(DOE and State of Colorado, 1989). The CDH/DOE Agreement states in Item C.7 "Source Reduction and Zero Discharges Study: Conduct a study of all available methods to eliminate Rocky Flats discharges to the environment including surface waters and groundwater. This review should include a source reduction review."

The downstream erosion potential study was designed to investigate downstream surface-water channels under various assumed streamflow conditions for potential negative impacts that may be induced by zero-offsite water-discharge plan features. This included an evaluation of several aspects of downstream erosion potential, due to the increase or decrease in discharge flows (caused by recommended changes in the effluent characteristics recommended as part of the zero-offsite water-discharge strategies).

- Current thalweg alignment of the study streams were compared to the 1937 alignment. The comparison established the "trend" of changes to the alignment which have occurred over the past 50 years. This was useful in assessing areas that are unstable, and therefore, prone to erosion;

- Existing models (HEC-2, Westminster Area FHAD) of the downstream surface water streams were employed using revised flow regimes to assess changes in the channel velocities under various streamflow scenarios;

- Anticipated and existing velocities were compared to estimate changes in erosion potential in various segments; and

- An outline of generic mitigation methods that may be used to counteract any identified increases in erosion potential that may result from implementation of a zero-offsite water-discharge plan alternative was prepared

The Rock Creek area between the Boulder Turnpike (U.S. Highway 36) and the confluence with Coal Creek had a Flood Hazard Analysis prepared by the US Soil Conservation Service (SCS, 1976) which should still be applicable (Figure 5). The 100-year flow rate in this area ranges from 5,500 cubic feet per second (cfs) to 7,000 cfs for future developed conditions. There were no published reports found which have calculated the flow rates for that segment of Rock Creek upstream of U.S. Highway 36.

The Big Dry Creek FHAD (Greiner, 1988) documented conditions in the regulatory floodplain and floodway for Walnut Creek from Simms Street to the confluence with Big Dry Creek, and Big Dry Creek (as well as other tributary streams) from Standley Lake downstream to the crossings with I-25 assuming ultimate developed (approved DRCOG planning populations) basin conditions. For this task, the RFP was presumed to remain indefinitely and the immediate surrounding area would remain undeveloped. Figure 4 shows the study limits of each stream and a vicinity map.

In conjunction with UDFCD (1969) guidelines and FEMA requirements, the HEC-2 computer model (USACOE, 1988) was used to obtain water-surface profiles (Greiner, 1988). Although significant flood-attenuation benefits were cited for Great Western Reservoir and Standley Lake in the FHAD and the cities of Broomfield and Westminster have provided "adequate assurances" to <u>maintain</u> historic flood attenuation for these reservoirs, the modeling assumed that the reservoirs were both full and the starting 100-year water-surface elevations were set at the existing spillway elevation. Some flood attenuation benefits still exist under this assumed worst-case scenario.

The Outfall Systems Planning (OSP) study for Big Dry Creek (Muller, 1989) represents a master plan for the development of a major drainageway system throughout the planning area. This study area extended from Standley Lake and Great Western Reservoir to the Adams/Weld County Line at 168th Street, upstream from confluence with the South Platte River near Fort Lupton (Figure 4). It should be noted that the Walnut Creek upstream of Great Western Reservoir and Woman Creek upstream from Standley Lake were stream reaches not directly addressed, but merely were treated as inputs to these reservoirs.

The morphology of the study streams is a result of the water and sediment supplied to the reach and the effects of backwater created by undersized culverts. A qualitative geomorphological analysis of Rock Creek, Big Dry Creek and Walnut Creek was performed in order to study the impacts of the RFP improvements on channel stability. The focus of this analysis was on channel-bend stability and the potential for stream-channel lateral migration.

Appendix A contains results of the HEC-2 computer analysis for Big Dry Creek and Walnut Creek under assumed future land-use conditions (which assume no change at the RFP) and existing channel characteristics. Table A-1 provides the channel and overbank velocities for the 100-year frequency flood. Sections begin at I-25 and proceed upstream to the Great Western Reservoir and Standley Lake. The cross-section data and locations were obtained from the FHAD for Big Dry Creek (Greiner, 1988).

The three study streams have shown a tendency to change in response to changing upstream conditions and will continue to do so as the basins urbanize. Proper master planning of these streams taking into account the anticipated changes in land uses, and the subsequent changes to base flow rates, flood peaks and discharge durations will be necessary to adequately stabilize the channels or prevent developments to encroach within the "meander belt" of these streams. The proposed changes to the runoff characteristics of these watersheds is not expected to occur at the RFP as a result of the implementation of Zero-Offsite Water-Discharge strategies. Future land use modifications, channel improvements, and public works projects throughout the basins will each have an incremental impact to the equilibrium of the streams. The streams are expected to continue to adjust to the changing basin conditions as they have in the past.

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1.0 INTRODUCTION

1.1 BACKGROUND

Operations at the Rocky Flats Plant (RFP) have been curtailed since the 1989 regulatory actions at the Plant citing severe health, safety and environmental problems at the facility (DOE, 1989). Several intergovernmental agreements were developed in response to this situation to ensure compliance with state and federal health, safety and environmental laws and regulations prior to a full resumption of operations at the RFP.

This is a report for documenting the results of one of thirty identified tasks (ASI, 1990a) being conducted for, and in the development of a Zero-Offsite Water-Discharge Plan for Rocky flats Plant (RFP) in response to Item C.7 of the Agreement in Principle between the Department of Energy (DOE) and the Colorado Department of Health (CDH) (DOE and State of Colorado, 1989). The DOE/CDH Agreement states in Item C.7 "Source Reduction and Zero Discharges Study: Conduct a study of all available methods to eliminate Rocky Flats discharges to the environment including surface waters and groundwater. This review should include a source reduction review."

Other Zero-Offsite Water-Discharge Study tasks which affect this study or are affected by this study include the Water-Yield and Water-Quality Study of the Walnut Creek Woman Creek Watersheds (Task 4, ASI, 1990c); Confirmation of Rainfall/Runoff Relationships Study (Task 5, ASI, 1990i); Design Recurrence Intervals Study (Task 9, ASI, 1990d); Surface-Water and Ground-Water Rights Study (Task 14, ASI, 1991h); Alternatives to Zero Discharge Study (Task 17, ASI, 1991e); Temporary Water-Storage Capabilities Study (Task 21, ASI, 1991d); Bypass Upstream Flows Around Rocky Flats Plant Study (Task 24, ASI, 1991c); Feasibility of Ground-

Water Cutoff/Diversion Study (Task 26, ASI, 1991f); and Consolidation and Zero-Discharge Plan (Task 30, ASI, 1991k). Figure shows the interrelationship of the various zero-offsite water-discharge subordinate studies.

1.2 SCOPE AND PURPOSE

The downstream erosion potential study was designed to investigate downstream surface-water channels under various assumed streamflow conditions for potential impacts that may be induced by zero-offsite water-discharge plan features (ASI, 1990b). This study includes an evaluation of downstream erosion potential due to the increase or decrease in streamflows as a result of implementation of the preferred zero-offsite water-discharge alternatives.

Data and information sources relevant to quantifying the existing hydrological regimes of the streams upstream and downstream of the RFP, including existing and anticipated erosion characteristics, provide the focus of this study. A listing of preferred alternative zero-offsite water-discharge features has been developed in other tasks (ASI, 1991h) and are summarized herein. These features were assessed for their likely impacts to downstream channels.

1.3 ROCKY FLATS PLANT HYDROLOGIC SETTING

1.3.1 Drainage Basins

Figure 2 provides an overview of the RFP site, and the surrounding area. The RFP site is located on a plateau approximately 6,000 feet above mean sea level (ft MSL) in elevation and approximately 4 miles (mi) east of the eastern Front Range foothills. The RFP site occupies an area of over 6,500 acres (ac), with major buildings located within an area of approximately 400 ac known as the Controlled Area, with the surrounding area serving as a Buffer Zone.

Surface- and ground-water flows at the RFP generally are from west to east. Local ground-water hydrology is controlled by a thin gravelly alluvium of variable permeability. Groundwater is known to surface at seeps and springs within the natural stream channels traversing the site. The area is semi-arid with much of its average annual precipitation of 15 inches (in) falling as snow.

The RFP Controlled Area (Figure 2) is located on the eastern margin of an alluvial bench between two stream-cut valleys: North Walnut Creek and Woman Creek. North Walnut Creek joins South Walnut Creek east within the RFP site to form Walnut Creek (Figure 3) which flows into Great Western Reservoir and then southeasterly to Big Dry Creek (Figure 4). The quantity of water that enters Great Western Reservoir from the RFP area is relatively small, because of the small contributing surface drainage area relative to the larger quantity of the water entering this impoundment from front range canals and channels which divert water around the RFP site (ASI, 1990c). Figures 3 and 4 show the relationship of these downstream reservoirs to the RFP and the drainage basins surrounding them. Walnut Creek is tributary to Big Dry Creek. The confluence of these two streams is located about 3.1 miles downstream from Standley Lake (Figure 4). Water in the Walnut Creek basin moves through streams as well as man-made channels and culverts within the RFP area as a result of surface runoff following periods of rainfall and snow melt. Although Walnut Creek is generally ephemeral over its length, baseflow is supplied by seeps, springs, irrigation diversions, wastewater from various man-related activities, and overflows from the South Boulder Diversion Canal. The network of storm culverts within the Controlled Area of the RFP and RFP ponds along both South Walnut Creek and Walnut Creek (Figure 2) affect the rate of water movement in the basin (ASI, 1990f). Much of the water flowing in the South Walnut Creek and Walnut Creek basins is the result of imported water from Denver Water Board (DWB) water purchases and irrigation diversions from Coal Creek west of the RFP (ASI, 1990c). The general hydrologic relationships between the gaged streams of this complex system is discussed in Section 4.1.2.

The headwaters of Woman Creek is west of the RFP site and the stream flows eastward (Figures 2 and 3). Woman Creek discharges to Standley Lake (Figure 4) and, with Walnut Creek, forms Big Dry Creek. Although Woman Creek generally is ephemeral over its entire length, baseflow is supplied by seeps, springs, irrigation diversions, and overflows from the South Boulder Diversion Canal. Physical characteristics of drainage basins of selected locations with the Woman Creek Basin also are listed in Table 1.

Big Dry Creek originates immediately downstream from Standley Lake Dam (Figure 4). Big Dry Creek flows generally in a northeasterly direction to the South Platte River, which it enters near Fort Lupton, Colorado. There is a mixture of inputs and outputs of surface water throughout this stream reach including effluent discharges from several wastewater treatment plants. The cities of Broomfield, Westminster, and Northglenn operate wastewater treatment plants (WWTPs) in the Big Dry Creek basin (Figure 4). The Broomfield WWTP is located along Big Dry Creek near 124th Avenue. Westminster's WWTP is located at about 132nd Avenue and Big Dry Creek. Northglenn's WWTP is located one mile east of I-25 and along the Weld County Baseline Road. This latter WWTP discharges its effluent into the Bull Canal, with summer releases into Big Dry Creek for flow augmentation.

Rock Creek originates in the northwestern part of the RFP site and flows north from the site under State Highway 128. There are no reservoirs in place to attenuate the runoff and no diversions into this basin to increase the natural runoff. Rock Creek enters Coal Creek near Lafayette (Figure 5). Coal Creek then flows north to Boulder Creek near Erie.

All process and potable water at the RFP is purchased from the DWB. This water is imported from the South Boulder Diversion Canal (supplying Ralston Reservoir) for on-site treatment prior to use. The imported water has averaged approximately 130 million gallons per year (ASI, 1991h). The RFP has constructed several series of ponds in the stream cut valleys (and off-channel) to control releases of effluent and surface-water runoff from the site.

Table 1

Summary of Drainage-Basin Characteristics for Walnut Creek and Woman Creek In the Vicinity of Rocky Flats

Walnut Creek

Sub Basin Location	Drainage Area (mi^2)	Length (ft)	Slope (ft/mi)
Walnut Creek at Great Western Reservoir Dam	5.5	28,100	113
Walnut Creek at Indiana Street	2.9	22,600	128
Walnut Creek at Pond A-4[2)]	0.63	10,200	166
Walnut Creek at former USGS Gaging - Station 06720780	1.2	8,400	171
South Walnut Creek at Pond B-5[1)]	0.41	9,500	170
South Walnut Creek at former USGS Gaging - Station 06720790	0.35	7,900	160

Woman Creek

Sub Basin Location	Drainage Area (mi^2)	Length (ft)	Slope (ft/mi)
Woman Creek at Indiana Street	2.8	30,100	145
Woman Creek at former USGS Gaging - Station 06720700	2.1	23,600	156
Woman Creek at Pond C-1[2)]	1.7	21,700	156
Woman Creek at former USGS Gaging - Station 06720690	1.8	20,100	158
Woman Creek at Pond C-2[3)]	0.35	7,900	167

1) Does not include area upstream from the Walnut Creek Diversion Dam (ASI, 1991c).

2) Does not include area diverted into Pond C-2 by the South Interceptor Canal (ASI, 1991c).

3) Source: ASI (1991d).

Small amounts of ground water exist in the stream-related alluvium and colluvium in the valleys. Recharge is from precipitation, snowmelt, and water losses from ditches, streams, and ponds that intercept the alluvium. The water table in the alluvium fluctuates seasonally in response to recharge with the highest levels occurring in the spring (ASI, 1991f).

1.3.2 Opportunities and Constraints

In the context of the wide variety of factors which would or could impact the implementation of a zero-offsite water-discharge (ZOWD) plan for the RFP, a measurable change in downstream erosion potential is not likely to be a major determinant in the selection of a final set of ZOWD alternative plan features. Mitigation of erosion is not particularly difficult when compared with the potential technical, financial and political barriers to implementing the likely plan features. As such, this task provides a framework for the needs and the institutional issues associated with implementing required mitigation measures, but it is not likely to be an influential factor in the ZOWD selection of the alternative plan features. Opportunities to refine the plan to minimize these downstream impacts are addressed and constraints identified. However, with respect to downstream erosion potential, these constraints probably do not constitute "fatal flaws" in the implementation of an alternative.

2.0 FEDERAL, STATE, AND LOCAL AGENCY INVOLVEMENT

Many Federal, State, and local agencies are involved in the planning, analysis, implementation and funding of projects related to major drainageways and their erosion potential. Many of these agencies and their involvement in major drainageway erosion potential are discussed here.

2.1 FEDERAL AGENCIES

The Federal Emergency Management Agency (FEMA) is responsible for developing floodplain-delineation studies in the United States for purposes of risk assessment, insurance requirements and other related needs. FEMA publishes Flood Insurance Rate Maps (FIRMs) of all major streams in a drainage basin, which provide the current limits of the 100-year floodplain according to FEMA criteria.

The U.S. Department of Agriculture's (USDA's) Soil Conservation Service (SCS) provides detailed guidance for assessment and monitoring of erosion controls from various agricultural land uses and for developing land. For Rock Creek, a Flood Hazard Analysis (SCS, 1976) has been completed for the reach between the Boulder Turnpike (U.S. Highway 36) and the confluence with Coal Creek. This work provides a critical input into an assessment of the erosion potential within the Rock Creek basin (especially rural areas) that affects the sediment transport to the surrounding streams (See Section 4.3.1).

The U.S. Environmental Protection Agency (EPA) is responsible for maintaining and/or restoring surface-water quality at standards which permit it to meet the uses required by Federal regulations. As such, it is intimately involved in programs to manage all point and nonpoint sources of pollution within a basin. Much of the early effort by EPA has focused on the control of point sources such as industries and municipal sewage treatment plants. However, much more interest in recent years has been directed towards the control of nonpoint sources of pollution such as irrigation return flows, erosion, atmospheric deposition, and urban runoff. A great deal of time and effort has been spent trying to quantify the extent of these problems and possible control measures available to address the problems. The EPA is starting to regulate directly urban runoff sources through the development of stormwater NPDES discharge permits for major storm sewer systems, construction activities and industrial sources (CFR, 1990). Direct regulatory control over the other nonpoint sources is still in the formative stages and tends to follow recommendations for "best management practices" (BMP) rather than performance standards. Significant stream-channel erosion may preclude a stream from continuing to meet applicable stream water-quality standards which would be of concern to the EPA. EPA is also the lead regulatory agency in water-quality issues for Federally-owned facilities such as the RFP.

The U.S. Geological Survey (USGS) has been involved in the monitoring and measurement of surface hydrology and water quality for surface and ground water. This mission has resulted in a relatively large statistical database of the quantity and quality of surface water in the United States which is available from the STORET system. The U.S. Geological Survey (USGS) has collected suspended sediment data at 243 sites in Colorado. These data are stored in the USGS Water Data Storage and Retrieval System (WATSTORE) and are available to the public. Lists of the sediment data-collection sites as well as the suspended-sediment concentrations, suspended-sediment discharge, water discharge, and occasionally suspended-sediment or bed-material-size distributions are available in the Water Resources Investigation Report 86-4344 (Elliott and others, 1986).

The USGS also has been involved in the quantification of runoff characteristics (both quantity and quality) from urban and rural settings. Some of this work occurred in conjunction with the EPA in the National Urban Runoff Program (NURP).

2.2 STATE AGENCIES

The State of Colorado's Division of Water Resources within the Department of Natural Resources is responsible for management of water within the state including flow monitoring, flood studies, water rights and the approval of the design and construction of control structures including reservoirs. The Water Quality Control Division of the CDH is the lead agency for water-quality issues in the state (non-federal facilities) including monitoring, NPDES permitting, non-point source pollution and the design and construction of water and wastewater treatment facilities. The Colorado Water Conservation Board (CWCB) is concerned with the development and utilization of water within the state and is therefore intimately involved in such areas as reservoir planning, design, construction and operation.

2.3 REGIONAL AGENCIES

The lead regional agency involved with drainage, channel improvements, and flooding in the Denver area is the Urban Drainage and Flood Control District (UDFCD). Although the UDFCD is tracking the water-quality issues involved in urban runoff control, the lead regional agency for water-quality issues, including erosion protection from developing areas, is the Denver Regional Council of Governments (DRCOG).

2.3.1 Urban Drainage and Flood Control District (UDFCD)

The UDFCD conducts detailed hydrologic basin studies within the District (in conjunction with FEMA) for the purposes of better qualification of hydrologic conditions including flood potential, and the design and construction of stream improvements and other control measures such as detention facilities to mitigate the impacts of runoff and flooding. In the area of the RFP, the most critical UDFCD studies impacting the area is surface streams are the Flood Hazard Area Delineation (FHAD) for Big Dry Creek and Tributaries (Greiner, 1988) and a study titled "Outfall Systems Planning (OSP), for Big Dry Creek [ADCO] and Tributaries" (Muller, 1989). These two studies collectively cover the Walnut Creek and Big Dry Creek basins from Great Western Reservoir and Standley Lake to the northern District boundary at the Weld County line. Figure 6 shows the limits of the study area for the OSP study. For Rock Creek, a Drainage Master Plan for Rock Creek and Coal Creek (EDAW, 1987) has been prepared including the reach of Rock Creek between the U.S. Highway 36 and its confluence with Coal Creek.

2.3.2 Denver Regional Council of Governments (DRCOG)

The Denver Regional Council of Governments (DRCOG) is the lead agency dealing with regional water-quality issues, both from point source and non-point source perspectives. Area-wide planning for water quality under Section 208 of the Federal Clean Water Act is managed by DRCOG. This involves the detailed monitoring, planning and development of control strategies to allow the surface waters of the region to meet desired or specified water-use objectives. In the area of non-point source pollution, the emphasis has been on monitoring and the development of BMP's to control contamination at the sources. Relevant to this, a considerable effort has been directed at the quantification and control of erosion from developing areas of the region. This has included detailed surveys on the erosion-control practices of the DRCOG-member cities and counties and the dissemination of a BMP guideline for the control of erosion and sedimentation.

The erosion-control report (DRCOG, 1988) was designed to identify which communities within the DRCOG had erosion-control programs, why some communities do not believe that such a need for such programs exists, and which communities believe they need a program but for various reasons have not been able to initiate one. The cities/towns in the Denver metropolitan area without an erosion-control program (ECP) included the City of Arvada, where City officials had considered an ECP but rejected it due to anticipated enforcement problems. Limits of the city of Arvada contain four major streams and numerous gullies and ditches that run through the City where bank erosion is apparent. The Best Management Practices Manual for the Control of Erosion and Sedimentation in the Denver Region (DRCOG, 1980) provides a framework for analyzing erosion potential and a detailed outline of the minimum components for an erosion-control plan, including descriptions of the types of control measures that should be employed.

2.4 LOCAL GOVERNMENTS

The primary local government entities involved in this study are the cities of Arvada, Broomfield, Lafayette, Thornton and Westminster. These entities are interested in both the protection of their drinking water-supply sources and in the downstream pollution, flooding and erosion issues associate with the streams. Broomfield has entered into a tentative agreement with the DOE to sell Great Western Reservoir to the DOE and obtain an alternative water supply source (such as a direct diversion system from Carter Lake)(DOE, 1991). Westminster remains very concerned about the water quality of Standley Lake as it may impact its drinking water supplies and the flooding characteristics and erosion potential of Walnut Creek and Big Dry Creek.

3.0 SEDIMENT AND SURFACE-WATER RELATIONSHIPS

The issues of area morphology and downstream erosion potential are driven by complex interactions of hydrologic and sediment-transport relationships. As such, the studies important to this task relate to basin hydrology, including base flows, flood potential, control structures, sources of sediment loads from point and non-point sources and the relationship of various transport mechanisms.

3.1 OVERVIEW OF EROSION/AGGRADATION AND SEDIMENT CONCEPTS

Channel aggradation or degradation occurs when sediment transport and water flow are not in equilibrium. This may occur when the volume or velocity of flow in a stream has changed. Natural streams have adjusted over time to the quantity and velocity of runoff that normally occur in the watershed. The vegetation and rocks lining the channel banks and bottom are sufficient to minimize channel and stream-bank erosion under these quasi steady-state conditions. However, changes in the upstream hydrologic regimes can cause either an increase or decrease in peak flows during storms and result in a change stream velocity. Either of these conditions can disrupt the equilibrium of the stream and cause changes to the streambed and banks. The changes may be defined as degradation, aggradation, and lateral migration. Degradation and lateral migration can endanger adjacent property, bridges, and other hydraulic structures while aggradation can reduce flood channel capacity, increase lateral erosion, and increase the flooding potential. Common points where erosion occurs include stream meanders and at channel constrictions, such as where bridges cross a stream. Aggradation also may occur at points where the stream velocity decreases. Examples include points where the channel grades flatten, the low flow channel widens, or a channel blockage causes a backwater effect.

It is necessary to characterize both upstream and downstream channel controls to address the potential for channel erosion or aggradation in a particular stream segment. In the simplest case, conditions within a given stream segment reflect upstream geology, morphology, and hydrology (the hydrology itself may be strongly influenced by drainage-basin morphology). Sediment transport is affected by the upstream drainage basin area (sediment sources), the sediment transport zone (stream segment where the input of sediment can equal output), and the sediment sink (area of sediment deposition) (SLA, 1982).

River systems are an integral part of the fluvial ecosystem. Streamflows, sediment transport rates, and channel morphology reflect the major responses resulting from river utilization activities. Analysis using principles of stream mechanics, that is a dynamic approach as compared to a static, rigid boundary approach, can provide a more realistic understanding of channel response to man-induced changes.

The discharge rate that has the greatest influence on the configuration of the low flow channel, and therefore the erosive force that shape that channel is called the "dominant" discharge (Leopold, 1966). The channel will be enlarged until a stable condition is reached. The discharge filling the channel can maintain the channel at its present cross section without scour or deposition. Also, it is not exceeded frequently enough for berm build-up to be appreciable. This discharge can, therefore, be conveniently adopted as the dominant discharge. The changes in peak 100-year flow rates will have a lesser impact to the erosion potential than the changes to the baseflow rates, since the flood events are much rarer.

In general, bends are formed by the process of erosion and deposition. Erosion without deposition to assist in bend formation would result only in escalloped banks. Under these conditions the channel will simply widen until it becomes so large that the erosion terminates. As a meandering river system moves laterally and longitudinally, the meander loops move at an unequal rate because of the unequal erodibility of the banks. This causes a tip or bulb to form and, ultimately, this tip or bulb is cut off. After the cutoff has been formed, a new bend may slowly develop.

Frequency plays an important part in defining the dominate discharge. When the natural river has formed a stable, single channel with stable berms of flood-plains, the discharge which fills the channel is the dominate discharge. Some higher frequency floods many overtop the berms or cause some bank erosion. The dominant discharge has a tendency to fill up the collapsed bank and maintain its own water course, channel cross-section, channel bed grain size and channel slope.

3.2 TASK METHODOLOGY

This study was designed to assess existing and anticipated impacts to downstream surface water channels that may be induced by alternative zero-discharge plan features and potential methods that could be employed to mitigate these impacts. As such, this study task is designed with the following strategy and approach (ASI, 1990b):

- Quantify the existing hydrologic regime in the downstream surface water channels from existing Flood Hazard Area Delineation (FHAD) and Floodplain Master Plan Studies.
- Determine the relationship between flow hydrographs that leave the RFP and reach these downstream drainage areas.
- Estimate characteristics of the stream channels relative to soil types, degree of channelization and degree of surrounding urbanization.
- Estimate the resultant changes in the hydrographs of flows that leave the RFP under various storm events with implementation of recommended zero-offsite water-discharge features (such as new or modified diversions, new or additional reservoir storage facilities, change in the operational characteristics of existing storage reservoirs, etc.) and the impact of these changes on the downstream hydrographs.
- Compare the current thalweg alignment of the study streams with the 1937 alignment. This will establish the "trend" of changes to the alignment which have occurred over the past 50 years. This is useful in determining areas that are unstable, and therefore, prone to erosion.

- Re-run existing models (HEC-2, Westminster Area FHAD) of the downstream surface water streams with revised flows to assess changes in the channel and overbank velocities under various streamflow scenarios.

- Compare the new velocities with existing velocities and determine estimated change in erosion potential in various segments using the channel characteristics described above.

4.0 CURRENT HYDROLOGIC-SEDIMENT RELATIONSHIPS NEAR THE RFP

4.1 AREA HYDROLOGY

4.1.1 Rock Creek Drainage Basin

The Rock Creek area between the Boulder Turnpike (U.S. Highway 36) and the confluence with Coal Creek had a Flood Hazard Analysis prepared by the US Soil Conservation Service (SCS, 1976) which should still be applicable (Figure 5). The 100-year flow rate in this area ranges from 5,500 cubic feet per second (cfs) to 7,000 cfs for future developed conditions. There were no published reports found which have calculated the flow rates for that segment of Rock Creek upstream of U.S. Highway 36.

A Master Planning Study (EDAW, 1987) was prepared for this same area, which essentially established the basis for a trail-and-park system along the stream corridor. The UDFCD does not have any HEC-2 modeling runs available for this stream corridor that occurred in either of these studies.

4.1.2 Walnut Creek Drainage Basin Including Great Western Reservoir

A schematic diagram (Figure 7) has been provided to graphically show the interrelationship of the surface water channel and irrigating ditches. Until September 1974, Walnut Creek's flows were contributions from a drainage an area of about 1.24 mi^2 above the U. S. Geological Survey (USGS) gaging station 06720780 (Figure 3). The natural streamflow of the basin was augmented by diversions from Coal Creek through the Upper Church and McKay (Zang) ditches (Figure 3). In September 1974, the Walnut Creek Diversion Dam and McKay Bypass Canal (Figure 3) were constructed to route the McKay Ditch flows north of the RFP Controlled Area. The McKay Bypass joins a small unnamed tributary of Walnut Creek which re-enters the Creek about 1,200 feet (ft) downstream from the confluence of South Walnut Creek and Walnut Creek (Figure 3).

The Walnut Creek Diversion Dam and McKay Bypass effectively intercept all of the streamflow of Walnut Creek upstream from that diversion. The remaining drainage basin area at the inactive USGS gaging station 06720780 was about 0.8 mi^2, according to Hurr (1976). Currently, the drainage area upstream from the South Boulder Diversion Canal (Figure 3) is not included in this drainage area.

The inactive USGS gaging station 06720780 on Walnut Creek operated from about July 1972 until November 1975. Measured discharges at that Walnut Creek site are summarized in Table 2. After construction of Pond A-4 (Figure 3) in about 1980, discharge measurements have been made downstream of Pond A-4 by RFP personnel. Much of the measured water from Pond A-4 is the result of captured surface-water runoff and ground-water inflows which originate on the RFP site. Water from other drainage basins also may be included, because water may be routed from South Walnut Creek into Walnut Creek via a series of pipes. Additionally, water pumped from Pond C-2 (Figure 3) also may flow into Pond A-4 and affect monitored flows downstream. The water from Pond C-2 is water which otherwise would have discharged into Woman Creek but is currently intercepted by the South Interceptor Canal (Figure 3). Because Pond A-4 currently is the location of water treatment prior to release under a National Pollutant Discharge Elimination System (NPDES) permit, the measured discharges downstream from Pond A-4 also may include treated STP effluent.

South Walnut Creek above USGS gaging station 06720790 (Figure 3) formerly had a drainage area of about 0.46 mi^2 (Hurr, 1976). Re-routing of runoff within the RFP Controlled Area between about 1976 and present has reduced the effective drainage area of this stream to about 0.35 mi^2. The USGS station on South Walnut Creek operated from about July 1972 through December 1974. The stream flows at this station are summarized in Table 2. In about 1980, Pond B-5 was constructed as a storage pond in South Walnut Creek. Discharges currently are monitored by RFP personnel downstream from Pond B-5 under an NPDES permit. Much of the water monitored downstream from Pond B-5 is STP effluent mixed with surface-water runoff from the RFP.

Table 2

Monthly and Annual Discharges at Selected Locations in the Walnut Creek Basin near Rocky Flats Plant

Summary of Measured Discharge Walnut Creek at Indiana Street[2] (ac-ft)

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1986	--[3]	--	--	--	--	--	--	--	--	--	19.5	11.8	--
1987	18.8	32.9	0	16.5	44.0	312	679	248	136	94.9	51.2	17.9	1,651
1988	0	5.6	0	0	23.1	92.1	254	647	223	0	0	45.5	1,290
1989	0	13.5	10.4	0	11.8	2.5	26.2	0.4	13.4	0	32.2	56.2	167
1990	19.5	0	0	0	0	48.9	108	45.7	0.2	0	65.2	14.4	302
1991	22.3	--	--	--	--	--	--	--	--	--	--	--	--

1) Source: EG&G Rocky Flats, Inc.

Summary of Measured Discharge Walnut Creek at USGS Gaging Station 06720780[1][2] (ac-ft)

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1972	--	--	0	--	--	--	--	--	11	0	10	8.7	--
1973	0.5	1.8	2.9	13	15	41	232	175	1.8	1.2	0	2.2	486
1974	3.9	2.3	16	53	37	92	--	--	--	--	0	0	--
1975	0	--	--	--	--	--	--	--	--	--	--	--	--

1) Source: Hurr (1976).

Summary of Measured Discharge South Walnut Creek at USGS Gaging Station 06720790[1][2] (ac/ft)

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1972	--	--	--	--	--	--	--	--	--	22	18	24	--
1973	13	21	17	20	16	22	48	193	24	16	8.2	19	417
1974	16	10	18	19	12	18	25	9.7	9.6	1.4	2.2	2.1	143

1) Source: (Hurr, 1976).
2) Values include water imported to the basin for domestic, industrial and irrigation uses.
3) -- No data available.

Streamflow in Walnut Creek at Indiana Street has been measured since October 1986 by RFP personnel. Discharges at this location represent a sum of the releases from Ponds A-4 and B-5 as well as runoff from the intervening drainage area between the two ponds and Indiana Street. The streamflows measured in Walnut Creek at Indiana Street are summarized in Table 2. These discharges include irrigation water diverted by the McKay ditch as well as surface-water runoff and STP effluent. Therefore, it is very difficult to estimate the quantity of water contributed by runoff alone as measured in the Walnut Creek basin. Parts of the Walnut Creek basin has been analyzed under the Big Dry Creek basin studies as explained in Section 4.1.3.

4.1.3 Big Dry Creek Including Woman Creek Tributary Basin and Standley Lake

Prior to July 1973, the area along the south side of the RFP Controlled Area was drained by Woman Creek above USGS gaging station 06720700 which measured runoff from an area of about 2.1 mi^2 (Figure 3). In July 1973, this gaging station (06720690), was moved upstream from Pond C-2 to a site where the drainage area was about 1.8 mi^2 (Figure 3). The two USGS gaging-station locations on Woman Creek were operated from about August 1972 through October 1975. A summary of measured discharges in Woman Creek at these two stations is given in Table 3.

In about 1980, the runoff from the south side of the RFP Controlled Area was diverted to an off-channel storage facility (Pond C-2) by construction of the South Interceptor Canal (Figure 3). Woman Creek was diverted around Pond C-2 by the Woman Creek Diversion (Figure 3). RFP personnel have measured discharge in Woman Creek at Pond C-1 (drainage area of about 1.7 mi^2 not including the area diverted to Pond C-2). Table 3 summarizes the Woman Creek discharges measured at Pond C-1 for the period September 1986 through October 1990. These discharges include irrigation water diverted by the Kinnear Ditch (Figure 3).

Table 3

Monthly and Annual Discharges as Selected Locations in the Woman Creek Basin near Rocky Flats Plant

Summary of Measured Discharge
Woman Creek at Pond C-1[2]
(ac-ft)

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1986	--	--	--	--	--	--	--	--	--	--	--	0	--
1987	47.5	66.1	66.9	56.7	65.4	61.9	62.3	48.0	12.1	14.9	4.0	26.8	533
1988	63.8	59.4	66.6	52.4	66.3	63.5	63.5	61.3	42.1	0	0	0	539
1989	4.3	61.0	40.9	64.4	57.2	50.1	13.6	8.0	4.9[2]	0	0	0	304
1990	0	0	0	45.2	64.7	246	319	197	64.2	61.0	11.6	5.7	1,014
1991	23.9	--	--	--	--	--	--	--	--	--	--	--	--

1) Source: EG&G Rocky Flats, Inc.
2) Partial Month.

Summary of Measured Discharge
Woman Creek at USGS Gaging Station 06720690 and 06720700[1,2]
(ac-ft)

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1972	--	--	--	--	--	--	--	--	--	--	2.2	10	--
1973	11	29	26	37	50	67	1,020	709	--	10	8.1	7.4	1,975
1974	5.4	13	17	31	24	23	53	46	26	18	18	18	292
1975	19	--	--	--	--	--	--	--	--	--	--	--	--

1) Source: Hurr (1976).
2) Values include water imported to the basin for domestic, industrial and irrigation uses.

Big Dry Creek discharges into the South Platte River upstream from Fort Lupton (Figure 4). The Big Dry Creek drainage basin area at its mouth is about 113 mi^2. Since July 1987, the USGS operated a gaging station (06720820 on Figure 4) on Big Dry Creek located just upstream from the 120th Avenue bridge and about 5.2 mi downstream from Standley Lake. The Big Dry Creek drainage-basin area at this gage location is about 46 mi^2. A summary of the monthly and annual measured streamflows for the period from August 1987 through September 1990 is given in Table 4. The annual discharge in Big Dry Creek for the relatively short period of record at USGS gaging station 06720820 has averaged about 9,350 ac-ft/yr. These streamflows are affected by storage diversions, ground-water withdrawals, diversions for irrigation, and return flows from irrigated areas. The available USGS data at the gaging station are not indicative of natural yields from the Big Dry Creek drainage basin. The natural water yield of the Big Dry Creek basin is probably similar to other Front Range watersheds, i.e. relatively low, with water users historically relying upon imported water from Clear Creek, Coal Creek or other trans-basin and trans-mountain diversions. Most of the water entering the Big Dry Creek basin is diverted from Clear Creek through the Croke Canal and the Farmers Highline canals, and the Church Ditch. Some water also enters the basin from diversions from Coal Creek through the Last Chance, Kinnear, Upper Church and McKay ditches.

The City of Northglenn has taken periodic flow measurements at four sites other than the USGS gaging station. These four sites include (1) 112th Avenue and Sheridan Boulevard, (2) 132nd Avenue downstream from the Broomfield WWTP, (3) 136th Avenue and Washington Street, downstream from the Westminster WWTP, and (4) Weld County Road 6 downstream from the Northglenn WWTP. These measurements are summarized in Table 5 and generally represent low-flow conditions.

The Big Dry Creek FHAD (Greiner, 1988) documented conditions in the regulatory floodplain and floodway for Walnut Creek from Simms Street to the confluence with Big Dry Creek, and Big Dry Creek (as well as other tributary streams) from Standley Lake downstream to the crossings with I-25 assuming ultimate developed (approved DRCOG planning populations) basin

Table 4

Monthly and Annual Discharges at USGS Gaging Station 06720820, Big Dry Creek at Westminster, CO

(ac-ft)

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	TOTAL
1987	--	--	--	--	--	--	--	--	--	--	2,220	373	--
1988	612	270	74	61	58	87	142	1,650	3,950	3,280	2,600	452	13,240
1989	95	79	74	74	64	80	91	614	774	1,450	1,810	393	5,590
1990	423	120	80	102	95	693	633	916	2,350	1,200	1,520	1,080	9,210

Source: USGS Water-Resources Data for Colorado (Various Years).

Table 5

Summary of Measured Discharges at Selected Locations on Big Dry Creek [1)]
(cfs)

Date	112th & Sheridan	132nd Avenue	136th & Washington	Baseline Road
11/12/87	1	2	6	--
12/02/87	1	8	17	16
02/18/88	5	22	14	16
03/22/88	1	8	19	12
04/06/88	1	7	18	15
05/12/88	54	58	--	--
06/08/88	11	32	2	1
07/21/88	38	55	16	17
08/10/88	29	48	16	19
10/24/88	<1	8	5	26
11/03/88	<1	5	9	17
12/01/88	--[2)]	--	4	15
03/22/89	--	7	13	22
04/19/89	--	8	--	9
05/17/89	--	13	6	6
06/28/89	18	19	--	4
07/13/89	29	22	5	--
08/16/89	14	19	--	3
09/20/89	4	9	25	25
10/09/89	28	34	11	--
11/14/89	--	10	5	15

1) Source: (DOE, 1991).
2) Indicates no data available.

conditions. For this task, the RFP was presumed to remain indefinitely and the immediate surrounding area would remain undeveloped. Figure 4 shows the study limits of each stream and a vicinity map.

In conjunction with UDFCD (1969) guidelines and FEMA requirements, the HEC-2 computer model (USACOE, 1988) was used to obtain water-surface profiles (Greiner, 1988). Although significant flood-attenuation benefits were cited for Great Western Reservoir and Standley Lake in the FHAD and the cities of Broomfield and Westminster have provided "adequate assurances" to <u>maintain</u> historic flood attenuation for these reservoirs, the modeling assumed that the reservoirs were both full and the starting 100-year water-surface elevations were set at the existing spillway elevation. Some flood attenuation benefits still exist under this assumed worst-case scenario.

The Outfall Systems Planning (OSP) study for Big Dry Creek (Muller, 1989) represents a master plan for the development of a major drainageway system throughout the planning area. This study area extended from Standley Lake and Great Western Reservoir to the Adams/Weld County Line at 168th Street, upstream from confluence with the South Platte River near Fort Lupton (Figure 4). It should be noted that the Walnut Creek upstream of Great Western Reservoir and Woman Creek upstream from Standley Lake were stream reaches not directly addressed, but merely were treated as inputs to these reservoirs.

The OSP provides a basis for the sponsoring regional and local agencies to enable them, through their planning and development process, to ensure that an integrated drainageway system will result. Such a system is designed to provide compatibility between facilities in different cities or counties that would provide a uniform level of protection from flood hazards for the present and future property owners in the basin. The OSP inherently involves the use of erosion prevention in the design of the major drainage channels to convey flows from storm events and to prevent damage to adjacent properties.

Facilities were recommended for each sub-basin in the watershed which contains 130 ac or more of land area. Smaller subbasins are presumed to be served with local drainage facilities. The OSP is general enough to allow variations which would be better suited to individual developments but is specific enough to insure that any variations would be properly integrated into the planned drainage system.

For the OSP study, the watershed was divided into six major study basins and a drainage outfall network was identified for each one. Sub-basin runoff hydrographs were developed using the Colorado Urban Hydrography Procedure (CUHP), (UDFCD, 1985a) and the individual hydrographs linked using the modified Storm Water Management Model (UDSWM2) (UDFCD,1985b). The Big Dry Creek HEC-1 hydrology was developed as part of the Westminster Flood Hazard Area Delineation Study (FHAD) and was modified with this outfall plan to include the effects of inadvertent floodway storage preservation on Big Dry Creek and Walnut Creek.

The alternatives that were developed ranged from "no-action" to extensive channel improvements, and an intensive public involvement program helped to screen and select reach-by-reach selected plan features. In general, the majority of alternatives fell into three distinct categories as follows:

- Regional Detention Ponding -- This alternative frequently was found favorable in areas where land development had already occurred and in which drainage facilities were determined to be inadequate to convey the projected peak flows. The regional ponds would collect and release runoff at reduced flow rates, which could be handled by the existing facilities.

- Improved Channel Conveyance -- In many cases in which relatively little land development had occurred, existing channels had vacant land adjacent to them. The existing drainageways ultimately would be inadequate to carry the peak-flood flows generated by future development. The construction of grass-lined or earth-lined channels with adequate capacity and right-of-way was generally found preferable to regional detention ponding in relatively undeveloped areas when space was readily available.

- Floodplain Preservation and Floodplain Regulation -- These two approaches are closely related and refer to the maintenance of the natural status of a drainageway.

> These alternatives were dominant on Big Dry Creek, Walnut Creek, and a few of the major tributaries. The approach was to stabilize the channel to prevent excessive bed and bank erosion, to improve certain crossing structures to eliminate flooding, and to otherwise leave the channel in its natural condition.

Although constructed primarily for water supply, Great Western Reservoir and Standley Lake still provide significant flood-control benefits according to the OSP and FHAD hydrology studies. Spillway modifications are planned for both reservoirs, which will increase the 100-year flows downstream, although significant attenuation of the 100-year reservoir inflows still would occur. These spillway effects were included in the hydrology modeling. A State of Colorado Law states that owners of water supply and other non-flood control reservoirs are not required to provide flood-storage benefits, and may pass storm inflows directly through the reservoirs without attenuation. The UDFCD Board then passed Resolution Number 36 in 1986 which stated:

> "inadvertent flood routing provided by water supply and other non-flood control reservoirs shall not be considered in the hydrology and the flood hazard delineation downstream of these reservoirs unless adequate assurances have been obtained by the UDFCD Executive Director to preserve the flood-routing capability of the reservoirs."

The UDFCD has obtained "adequate assurances" with the involved parties, including the dam owners and the Cities of Broomfield and Westminster, which would state that the flood routing capabilities of both reservoirs will be preserved. The OSP was prepared on the presumption that these agreements will be completed and that Standley Lake and Great Western Reservoir would continue to provide the flood control as documented in the Westminster FHAD. However, the Westminster FHAD only provides for minimal attenuation, as both reservoirs were assumed full in the FHAD analyses at the time of the 100-year flood event.

Grass-lined open channels generally have been recommended for facilities which are to convey the 100-year flows, particularly where the available right-of-way already existed. Side slopes would be 4 to 1 or flatter, and trickle channels would convey up to 3 percent of the 100-year design flow. Maximum velocity and depth criteria used were 7 ft/s and 5 ft, respectively.

Appropriate drop structures would be required to maintain these criteria and control erosion. Maintenance access roads would be required to allow mowing, trash and debris removal, and drop structure maintenance. Rock-lined channels and concrete-lined channels would not be considered feasible unless certain unusual circumstances dictated their consideration.

Numerous irrigation ditches traverse the study area, and they are generally constructed in a manner which allows them to accept surface runoff on the upstream side. Because the ditches have generally small conveyance capacity when compared to runoff peaks, they tend to carry stormwater for relatively short distances to zones of restricted capacity. At such points, the stormwater would be spilled over the downstream bank onto properties which may not have been previously subjected to flooding. As a result, these ditches act to only transfer drainage problems. The UDFCD has adopted a policy of eliminating the transfer of drainage problems by ditches, by advocating special structures at locations where drainageways intersect ditches. The structures allow all flows in the drainageway to pass over or under the ditch, and cause the ditch to spill flows which would exceed the ditch's intended carrying capacity. The completion of these structures tends to keep the runoff problems where they belong and would eliminate any liability which the ditch companies may incur by accepting storm runoff.

4.1.4 Existing Streamflow Characteristics

Appendix A contains results of the HEC-2 computer analysis for Big Dry Creek and Walnut Creek under assumed future land-use conditions (which assume no change at the RFP) and existing channel characteristics. Table A-1 provides the channel and overbank velocities for the 100-year frequency flood. Sections begin at I-25 and proceed upstream to the Great Western Reservoir and Standley Lake. The cross-section data and locations were obtained from the FHAD for Big Dry Creek (Greiner, 1988).

4.2 POTENTIAL CHANGES TO THE HYDROLOGIC-SEDIMENT RELATIONSHIPS DUE TO IMPLEMENTATION OF VARIOUS ZOWD ALTERNATIVE FEATURES

4.2.1 Summary of Zero-Discharge Alternative Features

An important water-rights issue, which may affect the for potential downstream sediment aggradation/degradation is the amount of flow depletion caused the RFP operations to the existing stream system. Depletion is calculated as the water used minus the return flow, corrected for any lag time. Depletion to the stream, not water use, would determine how much augmentation water or replacement water must be provided. Zero-Offsite Water-Discharge Study Task 17 (ASI, 1991e) and Task 21 (ASI, 1991d) include a description of preferred alternatives for control of STP effluent, surface-water runoff, and ground water at the RFP. The nine preferred alternatives for temporary water storage for three RFP populations of 3,000 and 9,000 personnel and a shutdown population scenario for three types of storage facilities are summarized in Table 6. The three preferred alternatives for temporary water storage, depending upon storage facilities, for zero discharge at the RFP are summarized in Table 7.

At this time, it is unclear which alternative will be implemented, if any. Some alternatives, such as "temporary water storage" may increase or decrease the mean annual discharge, while other senecios, such as "by-pass upstream flows around RFP" may increase the flood peaks since that runoff is currently being detained in the RFP ponds or discharging to other locations. For this study, the baseflow downstream from the RFP is estimated to be about 10 cfs for both Walnut Creek and Big Dry Creek. For the future conditions, this baseflow may increase to 13 cfs or remain the same area absolute zero discharge for the RFP.

During a 100-year flood event, the alternatives studies in the Zero-Offsite Water-Discharge Plan will have little or no impact to the peak flow rates of Walnut Creek or Big Dry Creek downstream of Great Western Reservoir or Standley Lake, respectively. This is due to the flood

Table 6
Summary of Preferred Alternatives for Temporary Water Storage

GENERALIZED ALTERNATIVE	RFP PERSONNEL	ALT. NOS.	PREFERRED ALTERNATIVE DESCRIPTION	CONSTR. COSTS (Million $)	OM & R COSTS (Million $/Yr)
NEW OFF-CHANNEL RESERVOIR	3,000	0b and 1a	Off-channel storage of STP effluent (114 ac-ft/yr) with 108 ac-ft/yr reuse, off-channel storage of surface-water (125.3 ac-ft/yr) and ground water (10 ac-ft/yr), annual makeup water demand (4.73 ac-ft/yr). STP reservoir = 135 ac-ft, Runoff reservoir = 3200 ac-ft.	8.2	1.3
	9,000	0f and 1d	Off-channel storage of STP effluent (340 ac-ft/yr) with 325 ac-ft/yr reuse, off-channel storage of surface-water (125.3 ac-ft/yr) and ground water (10 ac-ft/yr), annual makeup water demand (140 ac-ft/yr). STP reservoir = 410 ac-ft, Runoff reservoir = 325 ac-ft.	17.5	2.7
	Shutdown	0a and 1j	Off-channel storage of STP effluent (114 ac-ft/yr) with no reuse, off-channel storage of surface-water (125.3 ac-ft/yr) and ground water (10 ac-ft/yr), no makeup water and spray evaporation (246.2 ac-ft/yr). STP reservoir = 1730 ac-ft, Runoff reservoir = 1900 ac-ft.	11.5	1.7
GREAT WESTERN RESERVOIR	3,000	0b and 2h	Off-channel storage of STP effluent (114 ac-ft/yr) with 108 ac-ft/yr reuse, off-channel storage of surface-water (139.8 ac-ft/yr) and ground water (10 ac-ft/yr), annual makeup water demand (4.73 ac-ft/yr). STP reservoir = 135 ac-ft, Diversion channel around Great Western Reservoir.	77.7	11.7
	9,000	0f and 2k	Off-channel storage of STP effluent (340 ac-ft/yr) with 325 ac-ft/yr reuse, off-channel storage of surface-water (139.8 ac-ft/yr) and ground water (10 ac-ft/yr), annual makeup water demand (140 ac-ft/yr) with downstream releases for water rights (111.6 ac-ft/yr). STP reservoir = 410 ac-ft, Diversion channel around Great Western Reservoir.	104.5	15.7
	Shutdown	0a and 2l	Off-channel storage of STP effluent (114 ac-ft/yr) with no reuse, off-channel storage of surface-water (139.8 ac-ft/yr) and ground water (10 ac-ft/yr), no makeup water. STP reservoir = 1730 ac-ft, Diversion channel around Great Western Reservoir.	76.3	11.4
TERMINAL PONDS	3,000	0b and 3c	Off-channel storage of STP effluent (114 ac-ft/yr) with 108 ac-ft/yr reuse, terminal pond storage of surface-water (125.3 ac-ft/yr) and ground water (10 ac-ft/yr), annual makeup water demand (4.73 ac-ft/yr) and downstream releases for water rights (99.8 ac-ft/yr). STP reservoir = 135 ac-ft, Raise Pond A-4 by 31 ft, Pond B-5 by 16 ft and Pond C-2 by 10 ft.	18.6	2.8
	9,000	0f and 3d	Off-channel storage of STP effluent (340 ac-ft/yr) with 325 ac-ft/yr reuse, terminal pond storage of surface-water (125.3 ac-ft/yr) and ground water (10 ac-ft/yr), annual makeup water demand (140 ac-ft/yr). STP reservoir = 410 ac-ft, No increase in pond sizes.	13.9	2.1
	Shutdown	0a and 3f	Off-channel storage of STP effluent (114 ac-ft/yr) with no reuse, terminal pond storage of surface-water (125.3 ac-ft/yr) and ground water (10 ac-ft/yr), no makeup water and downstream releases for water rights (99.8 ac-ft/yr). STP reservoir = 1730 ac-ft, raise Pond A-4 by 17 ft, Pond B-5 by 16 ft and Pond C-2 by 10 ft.	19.6	2.9

Source: ASI (1991d).

Table 7

Summary of Preferred Alternatives to Zero Discharge

STORAGE ALTERNATIVE	ALT. NOS.	PREFERRED ALTERNATIVE DESCRIPTION	CONSTR. COSTS (Million $)	OM & R COSTS (Million $/Yr)
NEW OFF-CHANNEL RESERVOIR	6a	Off-channel storage of STP effluent from 6300 RFP personnel (237 ac-ft/yr), surface-water runoff from 1.9 mi^2 (125.3 ac-ft/yr) with the 100-yr, 72-hr flood (425 ac-ft/yr), and ground water (10 ac-ft/yr) with April-through-October on-site spray evaporation in a lined pond (122.9 to 492.4 ac-ft/yr) (Zero Discharge).	4.5	0.7
GREAT WESTERN RESERVOIR	5b(a)	On-channel GWR storage of STP effluent from 6300 RFP personnel (237 ac-ft/yr), surface-water runoff from 5.5 mi^2 (279.7 ac-ft/yr) with the 100-yr, 72-hr flood (1143 ac-ft/yr), and ground water (10 ac-ft/yr) with on-site irrigation of pasture grass (144 to 576 ac-ft/yr).	80.9	12.1
TERMINAL PONDS	4d(a)	Terminal ponds storage of STP effluent from 6300 RFP personnel (237 ac-ft/yr), surface-water runoff from 1.07, 0.41, and 0.35 mi^2 (81.0, 39.2, and 34.8 ac-ft/yr) with the 100-yr, 72-hr flood (243, 106 and 76 ac-ft/yr) for Ponds A-4, B-5, and C-2 respectively, and ground water (10 ac-ft/yr) with a pipeline (187 to 374 ac-ft/yr) to the Denver Water Department Potable Reuse Plant, or with an irrigation water pipeline (164.6 to 658.3 ac-ft/yr) to the new Denver Airport.	146.0	21.9

Source: ASI, 1991e.

routing capabilities of these reservoirs which should attenuate any small change in peak inflow rates.

The peak 100-year flow rate on Walnut Creek upstream of the Great Western Reservoir, Woman Creek and Rock Creek will be directly affected since these stream segments are not controlled by reservoirs. The Kinnear Ditch by-pass (ASI, 1991c) will divert 2,450 cfs around the RFP and into Standley Lake. The peak 100-year release from the RFP into Woman Creek will be 570 cfs compared to a current condition release of 3,020 cfs.

The McKay Ditch by-pass (ASI, 1991c) will divert cfs 50 cfs, to Rock Creek during the 100-year storm, and allow the remaining 250 cfs to flow, around the RFP Controlled Area, back into Walnut Creek and into Great Western Reservoir. This results in a 50 cfs increase to Rock Creek and a 50 cfs decrease to Walnut Creek upstream of Great Western Reservoir.

4.3 REVIEW OF CUMULATIVE IMPACTS TO DOWNSTREAM REACHES

The morphology of the study-area streams is a result of the water and sediment supplied to the reach and the effects of backwater created by undersized culverts. A qualitative geomorphological analysis of Rock Creek, Big Dry Creek and Walnut Creek was performed in order to study the impacts of the RFP improvements on channel stability. The focus of this analysis was channel bend stability and the potential for lateral migration.

The data reviewed for the fluvial morphology analysis includes the 1937 and 1990 planimetric features visible on aerial photographs at a scale of 1-inch equals 600-feet for all streams; and 1974, 1976 and 1983 topographic mapping for a portions of Rock Creek and Walnut Creek and all of Big Dry Creek. The topography for Rock Creek was at a scale of 1-inch equals 400-feet and Walnut and Big Dry Creeks were at a scale of 1-inch equals 200-feet.

For this analysis, aerial photographs of the streams were obtained to determine the "historic" and "current" alignment and geometry of the low-flow channels. The "current", and "historic" conditions were obtained from aerial photographs, taken in 1990 and 1937 respectively. The aerial coverage for Rock Creek extended from the RFP to the confluence with Coal Creek, approximately 10 mi; Walnut Creek extended from Great Western Reservoir to its confluence with Big Dry Creek, approximately 4.5 mi; and Big Dry Creek extended from Standley Lake to I-25, approximately 8.5 mi.

The alignment of the stream thalweg from each photograph was compared to the other year's alignment to determine changes in channel curvature, sinuosity, and meander length. Also, the 1937 aerial photography was examined for indications of "ancient" oxbows that may still be evident in the undeveloped overbanks. This analysis is useful in determining areas that are unstable, and are prone to erosion. Of particular interest were stream-channel bends that have migrated, either upstream, downstream or laterally. Figures 8 and 9 are provided to show a comparison of the study stream thalwegs between 1937 and 1990 as determined from the aerial photographs.

4.3.1 Rock Creek Drainage Basin

The bankfull width is the width of the water surface before the river begins to overflow its banks. The bankfull width of Rock Creek is approximately 50 ft, but does reach 100 ft in places. There is no evidence that this dimension has changed appreciably since 1937.

The active bed width is that part of the streambed which transports bed load during floods and is not covered with herbaceous (leafy) vegetation. The active bed width varies from 5 ft to 50 ft throughout the study reach. This dimension seems to have remained constant, except downstream of road crossings that have been constructed since 1937. In these areas, the active bed width seems to have decreased since 1937.

Stream-channel bends are numerous throughout the study area, except in localized areas that have been straightened to accommodate street or railroad crossings. This has occurred at State Highway 128 (north boundary of the RFP), U.S. Highway 36 (Boulder Turnpike), upstream of U.S. Highway 287, upstream of the Burlington Northern Railroad (BNRR), and both upstream and downstream of Dillon Road. The natural bends show little sign of migration. There are isolated oxbows that have been "cut-off", because the low flow channel has breached the terrace between the converging bends. Many "ancient" meander scars are visible along Rock Creek along the east side of the BNRR, between U.S. Highway 287 and the confluence with Coal Creek.

Sinuosity is the ratio of low flow channel length to the valley length. From the confluence with Coal Creek to U.S. Highway 36, the low flow channel length is 8.0 mi and the valley length is 5.5 mi, resulting in a sinuosity of 1.45.

4.3.2 Walnut Creek Drainage Basin, Including Great Western Reservoir

The bankfull width of Walnut Creek is approximately 50 ft upstream of Great Western Reservoir and averages about 40 ft downstream of the reservoir. There is no evidence that this dimension has changed appreciably since 1937.

The active bed width upstream and downstream of Great Western Reservoir is about 10 ft. This dimension seems to have decreased slightly downstream of the reservoir, and significantly upstream of the reservoir where the active bed width was roughly 50 ft before the RFP existed (1937 photography).

Stream-channel bends are numerous throughout the study area. Immediately downstream of Great Western Reservoir, the low-flow channel is relatively straight. This is a man-made section constructed to accommodate the reservoir outlet works. Several other stream segments have been re-aligned in localized areas to accommodate street or railroad crossings. This has occurred at

Simms Street, W. 108th Avenue, State Highway 121 (Wadsworth Parkway), and U.S. Highway 36. The remaining natural bends show little sign of migration. There are several bends that have migrated downstream or laterally 50 to 100 ft. This condition is considered insignificant for this study.

From the confluence with Big Dry Creek to Simms Street, the low-flow channel length is 4.7 mi and the valley length is 3.4 mi, making the sinuosity 1.38.

4.3.3 Big Dry Creek Including Woman Creek Tributary Basin and Standley Lake

The bankfull width of Big Dry Creek averages 100 ft, but does reach 250 ft in places. There is no evidence that this dimension has changed appreciably since 1937.

The active bed width averages about 15 ft, but varies from 5 ft to 50 ft throughout the study reach. This dimension seems to have decreased from an average of about 40 ft in 1937.

Stream-channel bends are numerous throughout the study area, except in localized areas that have been straightened to accommodate street or railroad crossings. The natural bends show some sign of migration, particularly between Standley Lake and State Highway 121, and downstream of U.S. Highway 36 to W. 112th Avenue. Isolated oxbows occur that have been "cut-off", because the low-flow channel has breached the terrace between the converging bends. From Standley Lake to I-25, the low flow channel length is 12.8 mi and the valley length is 8.6 mi, making the sinuosity 1.49.

5.0 DETERMINATION OF SIGNIFICANT IMPACT AREAS

5.1 SEGMENTATION OF DOWNSTREAM CHANNEL AREAS

The RFP-area stream segments were classified according to readily available information and mapping. First, the segments were classified as bedrock-controlled versus alluvial. Bedrock-controlled channels are those so confined between outcrops of rock that the material forming the bed and banks determines the morphology of the channel. Alluvial channels are free to adjust dimensions, shape, pattern, and gradient in response to change and flow through channels with bed and banks composed of material transported by the stream under present flow conditions.

Objectively based criteria then were used to evaluate the existing erosion potential for the particular segments relative to the variables outlined, using either previously published reports or from the other data/information sources cited.

5.2 SOILS, CHANNEL CHARACTERISTICS, DEGREE OF URBANIZATION

5.2.1 Soils

Soils in the basin consist primarily of the SCS Soil Groups B and C with spotty areas of Group D soil upstream of Standley Lake (Greiner, 1988) and (SCS, 1975). These soils indicate a medium to low infiltration rate and a maximum channel velocity of 5 feet per second (ft/s) is recommended to prevent erosion, although velocities of 7 ft/s may be acceptable.

5.2.2 Channel Characteristics

The channels exist primarily in their natural meandering state, areas are increasing where channels are being improved for hydraulic capacity and stability. Section 4.3 discussed the channel characteristics for each study stream.

The culvert/bridge size at every major street crossing of Rock Creek, Walnut Creek and Big Dry Creek has been inventoried and listed on Table 8. Also included on this table is the size and type of culvert/bridge, its capacity at normal depth (entrance not submerged) and the 100-year flood peak, where information is available. Figures 8 and 9 show the location of each drainage structure.

The HEC-2 computer model, which was prepared in conjunction with the FHAD for Walnut Creek and Big Dry Creek, was revised to model the current baseflow conditions, and the increased baseflow anticipated from the implementation of the zero-offsite water-discharge alternatives plan at the RFP site. The velocities for each case, and the change in velocities are shown in Appendix B, Tables B-1 and B-2. As would be expected, an increase in flow results in an increase in velocity except in a few cases. The cases where the velocity decreased are primarily due to the increased wetted perimeter resulting in a less "efficient" cross-section for the larger flows. These cases are isolated and the decrease in velocity is very slight.

The visible erosion on all three streams studies is primarily in the form of channel degradation which is creating an incised low flow channel. This is not a recent occurrence, but has been occurring slowly over the life of the streams. The culvert/bridge structures actually prevent continued degradation at the place the structure is located. Between the structures, the streams are free to aggrade or degrade, in response to the changing equilibrium of the stream.

Most of the erosion is in the form of bank sloughing on the outside of the low flow channel bends. This is prevalent on Rock Creek, Walnut Creek and Big Dry Creek. The upper reaches of each stream seem more stable than the area further downstream. This is probable due to the increase baseflow as the watershed size increases downstream. Isolated areas have been protected using broken concrete and riprap erosion protection with varying degrees of success.

Table 8

Summary of Drainage Structures

Structure No.	Location	Size (w x h)	Type	Capacity (at Normal Depth) (cfs)	100-Year Flood (Currently) (cfs)
A.	**Rock Creek**				
1	U.S. Highway 128	8' x 10'	RCB	760	*
2	McCaslin Road	14' x 14'	RCB	2,100	*
3	Coalton Road	96" x 68"	Ellip. CMP	280	*
4	88th Street	84"	CMP	290	*
5	U.S. Highway 36	Double 12' x 10'	RCB	2,160	5,360
6	C & S Railroad	15' x 16'	Conc. Arch.	1,900	5,340
7	U.S. Highway 19	15' x 9'	RCB	1,200	5,310
8	South 96th Street	96"	CMP	400	5,280
9	U.S. Highway 287	84' x 14'	Bridge	5,000	5,230
10	Burlington Northern Railroad	86' x 12'	Bridge	4,800	5,220
11	Dillon Road	102" x 72"	Oval CMP	280	5,220
12	South 120th Street	45' x 12'	RCB	3,800	6,740
B.	**Walnut Creek**				
13	Simms Street	72"	CMP	200	1,930
14	108th Avenue	8' x 5'	RCB	260	3,900
15	U.S. Highway 121	Double 8' x 5'	RCB	520	3,900
16	C & S Railroad	60"	CMP	120	4,830
17	105th Avenue	60"	CMP	120	4,830
C.	**Big Dry Creek**				
18	U.S. Highway 121	14' x 8'	RCB	920	4,480
19	C & S Railroad	15' x 16'	Conc. Arch	1,900	4,480
20	Wadsworth Blvd.	14' x 7'	Bridge	690	3,220
21	U.S. Highway 36	Double 14' x 12'	RCB	3,360	7,570
22	Sheridan Blvd.	Double 108"	CMP	1,100	7,670
23	112th Avenue	24' x 10'	Bridge	1,400	7,670

Table 8 - Continued

Summary of Drainage Structures

Structure No.	Location	Size (w x h)	Type	Capacity (at Normal Depth) (cfs)	100-Year Flood (Currently) (cfs)
24	Federal Blvd.	12.5' x 14'	Bridge	1,230	8,080
25	120th Avenue	28' x 12'	Bridge	2,350	8,080
26	Zuni Street	31' x 4.8'	Bridge	870	11,190
27	128th Avenue	115.6' x 7.4'	Bridge	4,830	11,190
28	Huron Street	72"	CMP	200	11,190
29	I-25	83.5' x 9.5	Bridge	5,550	11,190

* No flows available

Many of the culverts and bridges are undersized and therefore create a backwater condition at the upstream side. This results in low velocities and sediment deposition at the entrance to culverts. The increased headwater depth required to force the flood waters through the culvert also result in excessive exit velocities which cause "plunge pools", or scour holes, at the downstream side of these structure. This condition was noted at the downstream side of most circular culvert structures on all three streams. The circular culverts tend to concentrate the high velocity jet streams which exit a culvert during large flooding events.

5.2.3 Degree of Urbanization

These channels meander through areas that have been rather rural in character but are increasingly becoming urbanized in many cases. The Rock Creek basin has experienced the least urbanization when compared to the three streams studied. There have been several major roads and a few developments constructed along Rock Creek, but the basin itself is relatively rural. Based on inspection of the available aerial photographs, this watershed has changed from approximately 5 percent developed in 1937 to roughly 25 percent developed in 1990. However, there is little evidence of manmade modifications to the stream itself, except in the vicinity of street and highway crossings.

Walnut and Big Dry Creeks watersheds have been altered quite extensively by the works of man. Great Western Reservoir and Standley Lake have been constructed on Walnut Creek and Big Dry Creek, respectively. Both streams have been crossed by major transportation corridors, and the watersheds have been urbanized. Based on inspection of the aerial photographs, Walnut Creek watershed has changed from approximately 5 percent developed in 1937 to roughly 50 percent developed in 1990, and Big Dry Creek watershed has changed from approximately 5 percent developed in 1937 to roughly 60 percent developed in 1990. However, there is little evidence of manmade modifications to either of these streams except immediately downstream of the reservoirs, and at an occasional street crossing.

5.3 CRITERIA FOR IMPACT ASSESSMENT

The areas considered most critical for their increased aggradation/degradation potential are those where the channel and/or overbank velocities are significantly increased, where there have been minimal channel improvements performed to stabilize the channel, and where there is increased urbanization to cause increased imperviousness and larger short-term runoff flows during storm events.

7.0 SUMMARY AND CONCLUSIONS

It is evident from the comparison of the 1937 and 1990 aerial photographs that changes have occurred to Rock Creek, Walnut Creek and Big Dry Creek. What is not evident is the degree of erosion that is resultant from man's activities, and what has occurred in spite of those activities. The culvert/bridge structures have acted as grade control structures and have stabilized the degradation in the immediate vicinity of the structure. However, many of the culverts are undersized, which results in debris blockage and aggradation on the upstream site, and excessive exit velocities and stream degradation on the downstream side. Bank sloughing is common on the outside of bends while sediment deposition is occurring on the inside of the bends.

The noted decreases in the active bed width since 1937 within the low-flow channels of Walnut Creek, downstream of Great Western Reservoir, and of Big Dry Creek, downstream of Standley Lake are probably a result of the decreased frequency and magnitude of flooding since the construction of these facilities. Rock Creek has remained relatively unchanged over the same period of time, as is indicated by examining the 1937 and 1990 aerial photography.

The three study streams have shown a tendency to change in response to changing upstream conditions and will continue to do so as the basins urbanize. Proper master planning of these streams taking into account the anticipated changes in land uses, and the subsequent changes to base flow rates, flood peaks and discharge durations will be necessary to adequately stabilize the channels or prevent developments to encroach within the "meander belt" of these streams. The proposed changes to the runoff characteristics of these watersheds will not only occur at the RFP as a result of the implementation of the Zero-Offsite Water-Discharge study. All future land use modifications, channel improvements, and public works projects throughout the basins will each have an incremental impact to the equilibrium of the streams. The streams will continue to adjust to the changing basin conditions as they have in the past.

8.0 ACKNOWLEDGEMENTS

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R. A. Applehans, PE/CE-ER

This study report has been prepared and submitted in partial fulfillment of the Zero-Offsite Water-Discharge Study being conducted by ASI on behalf of EG&G Rocky Flats, Inc. EG&G's Project Engineer was R.A. Applehans of Facilities Engineering, Plant Civil/Structural Engineering (PE/CE-ER).

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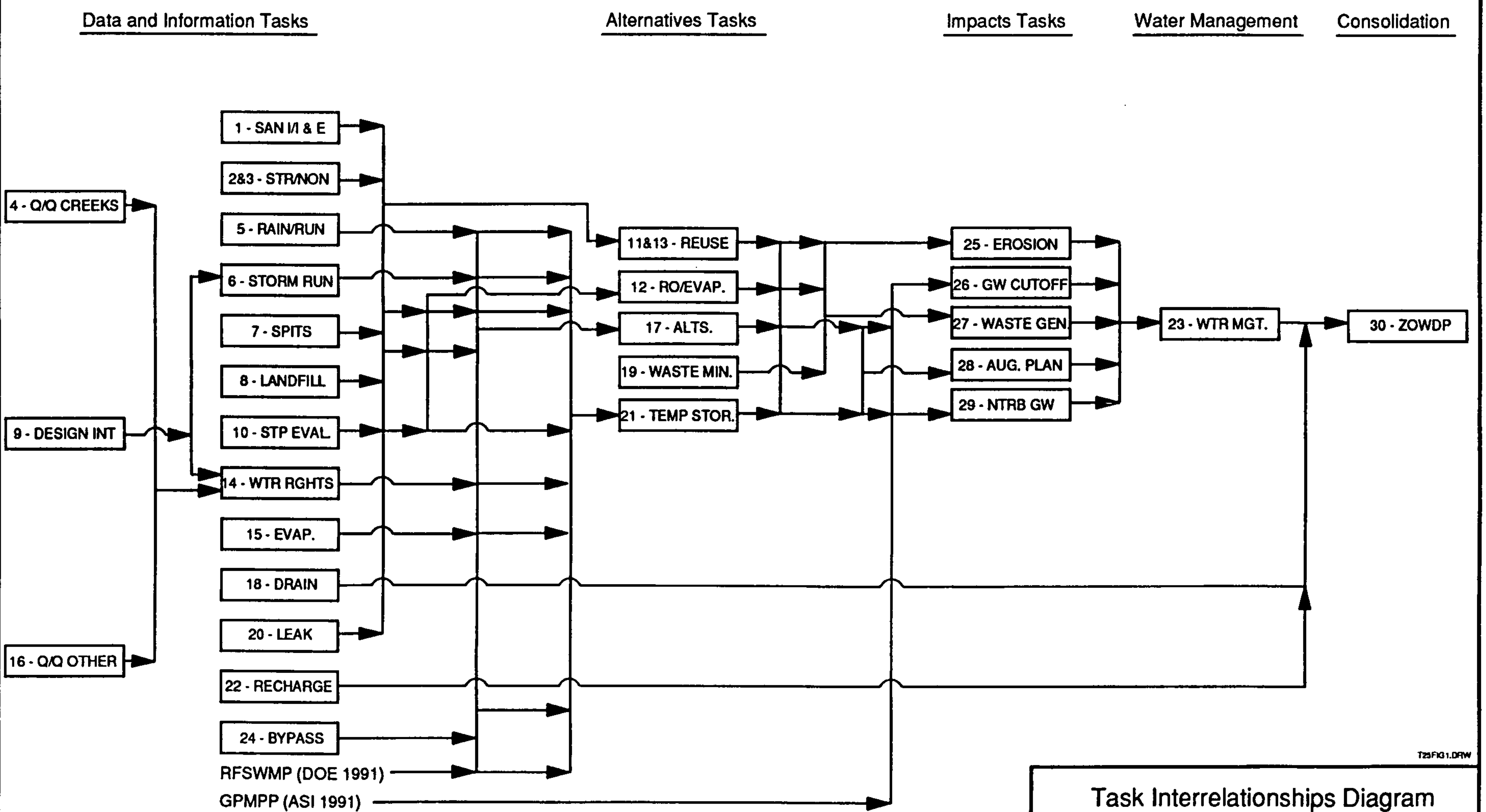
FIGURES



Task Interrelationships Diagram

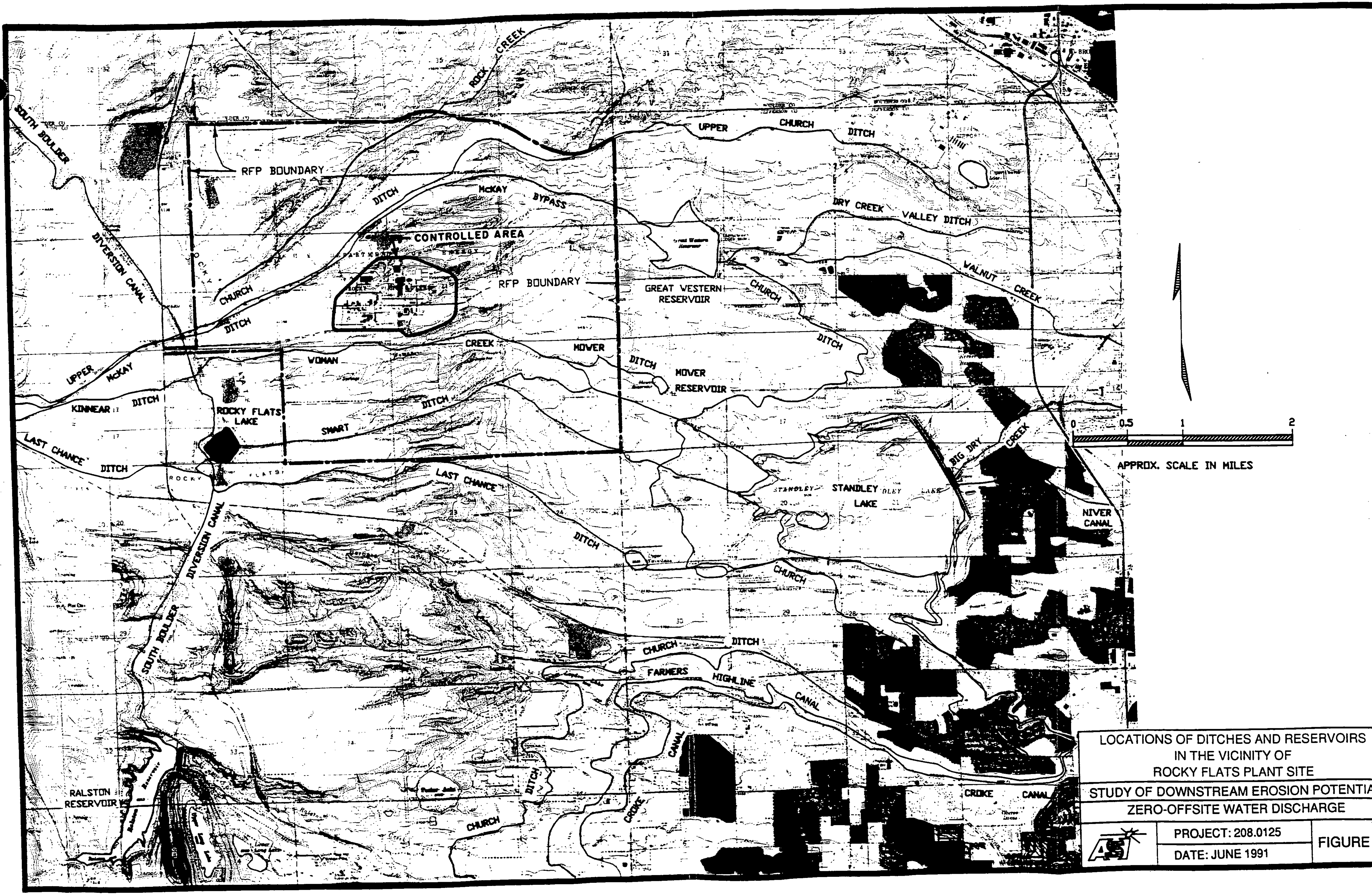
STUDY OF DOWNSTREAM EROSION POTENTIAL

Zero-Offsite Water Discharge

PROJECT 208.01.25

JUNE 1991

FIGURE 1

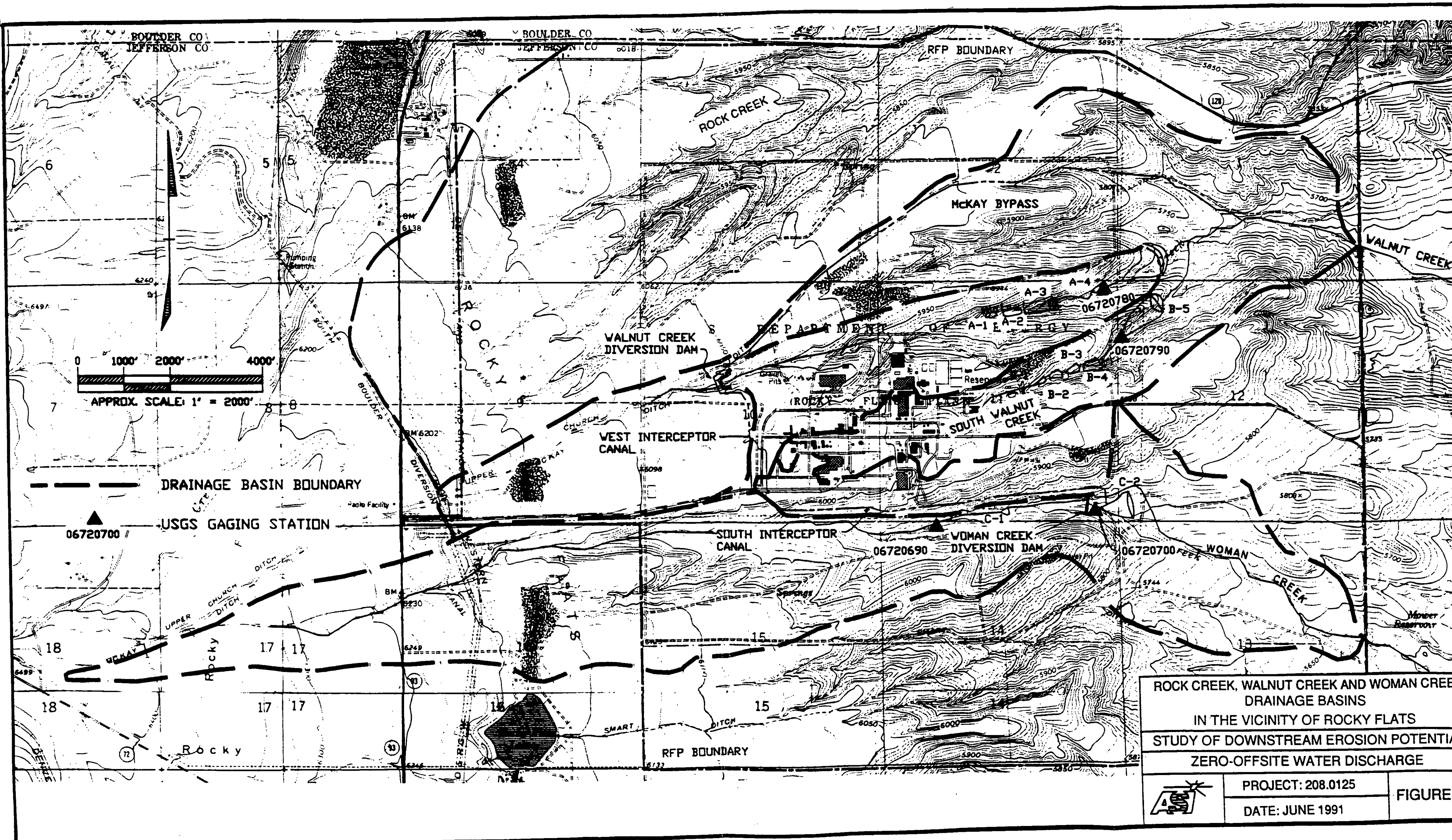


LOCATIONS OF DITCHES AND RESERVOIRS IN THE VICINITY OF ROCKY FLATS PLANT SITE

STUDY OF DOWNSTREAM EROSION POTENTIAL

ZERO-OFFSITE WATER DISCHARGE

FIGURE 2



ROCK CREEK, WALNUT CREEK AND WOMAN CREEK DRAINAGE BASINS IN THE VICINITY OF ROCKY FLATS

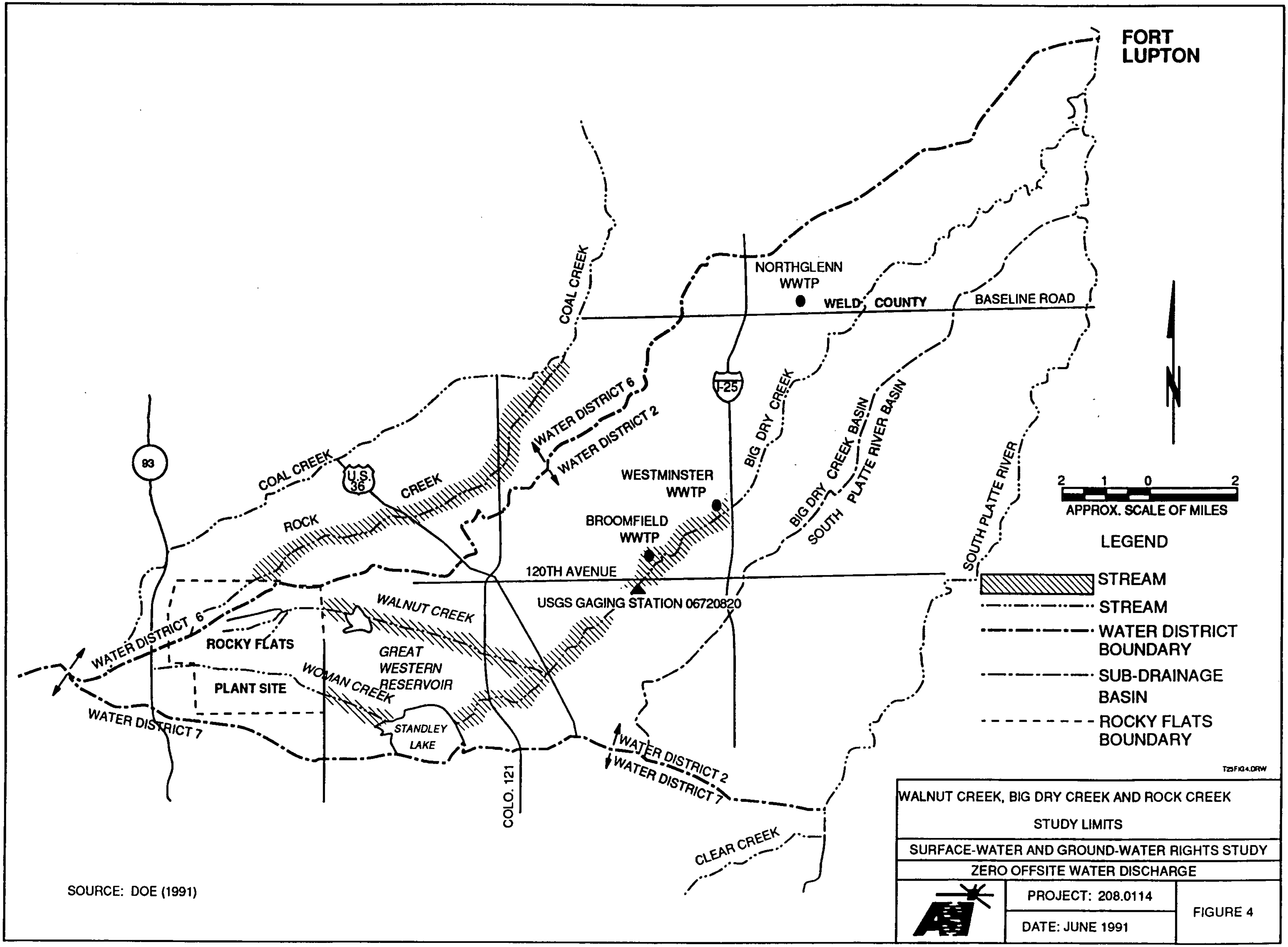
STUDY OF DOWNSTREAM EROSION POTENTIAL

ZERO-OFFSITE WATER DISCHARGE

PROJECT: 208.0125

DATE: JUNE 1991

FIGURE 3



SOURCE: DOE (1991)

WALNUT CREEK, BIG DRY CREEK AND ROCK CREEK

STUDY LIMITS

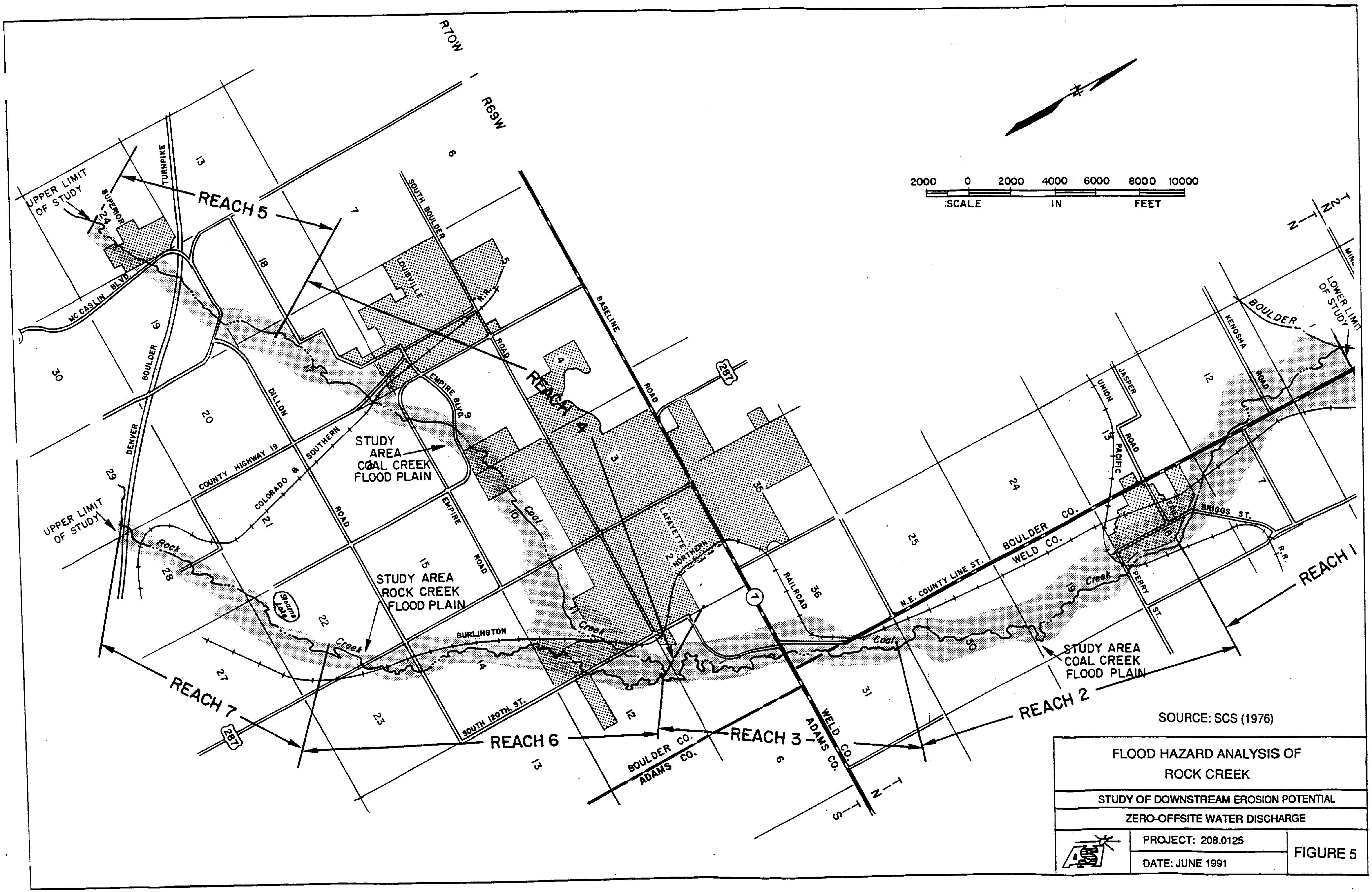
SURFACE-WATER AND GROUND-WATER RIGHTS STUDY

ZERO OFFSITE WATER DISCHARGE

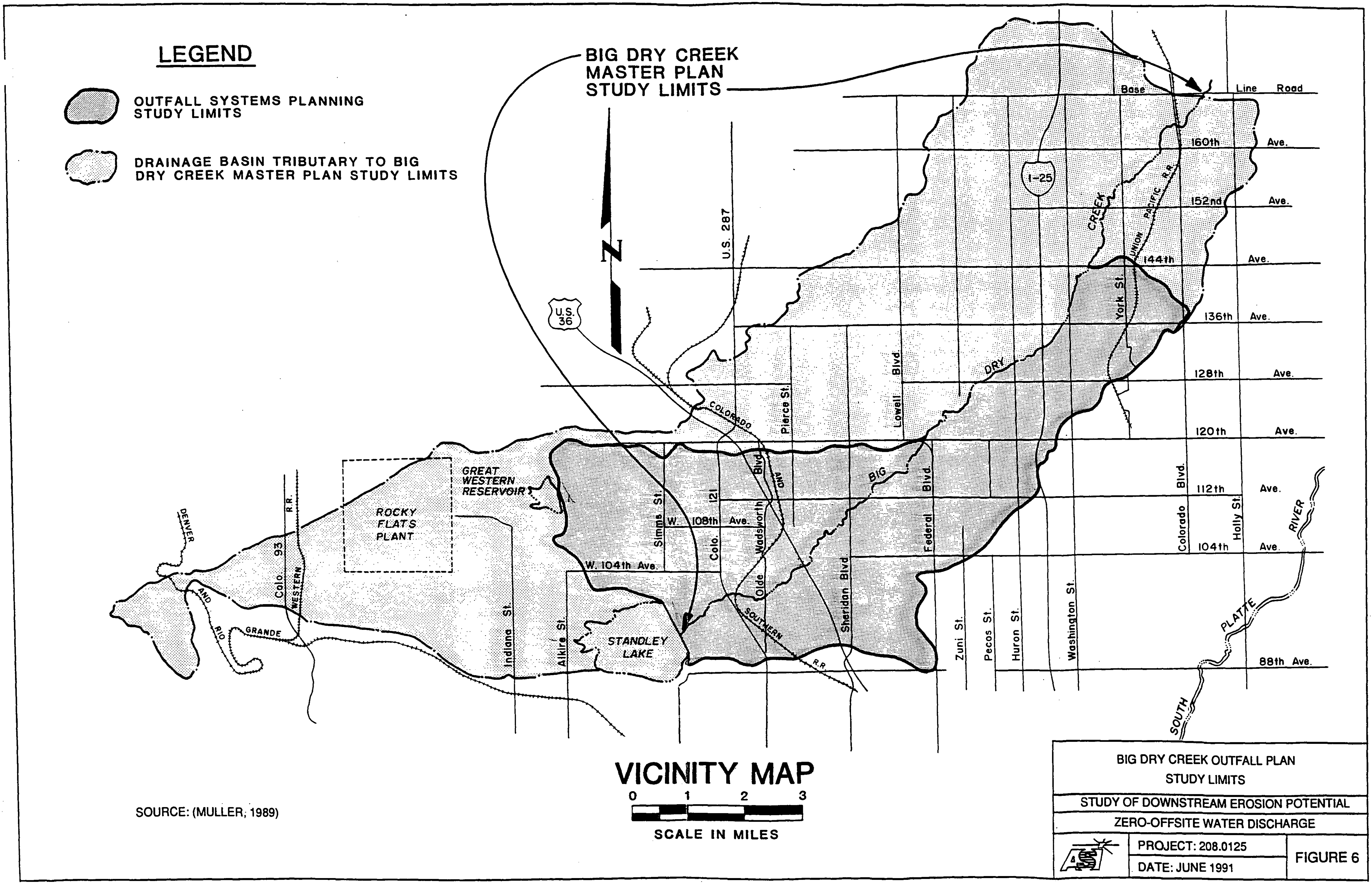
PROJECT: 208.0114

DATE: JUNE 1991

FIGURE 4



FLOOD HAZARD ANALYSIS OF ROCK CREEK	
STUDY OF DOWNSTREAM EROSION POTENTIAL	
ZERO-OFFSITE WATER DISCHARGE	
PROJECT: 208.0125 DATE: JUNE 1991	FIGURE 5

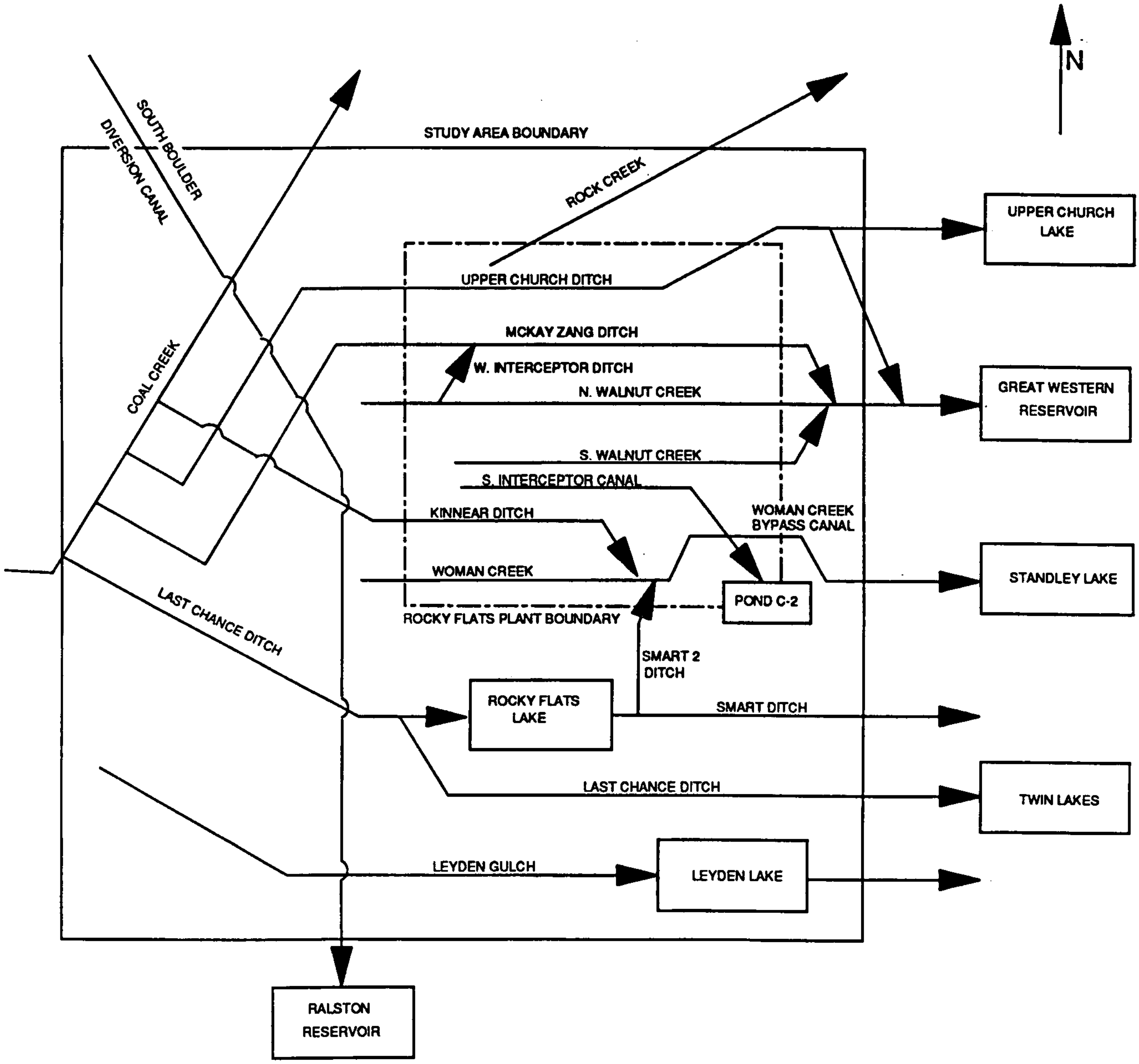


BIG DRY CREEK OUTFALL PLAN
STUDY LIMITS

STUDY OF DOWNSTREAM EROSION POTENTIAL
ZERO-OFFSITE WATER DISCHARGE

PROJECT: 208.0125
DATE: JUNE 1991

FIGURE 6



ADAPTED FROM HURR (1976).

T25FIG7.DRW

SCHEMATIC DIAGRAM OF SURFACE-WATER SYSTEM

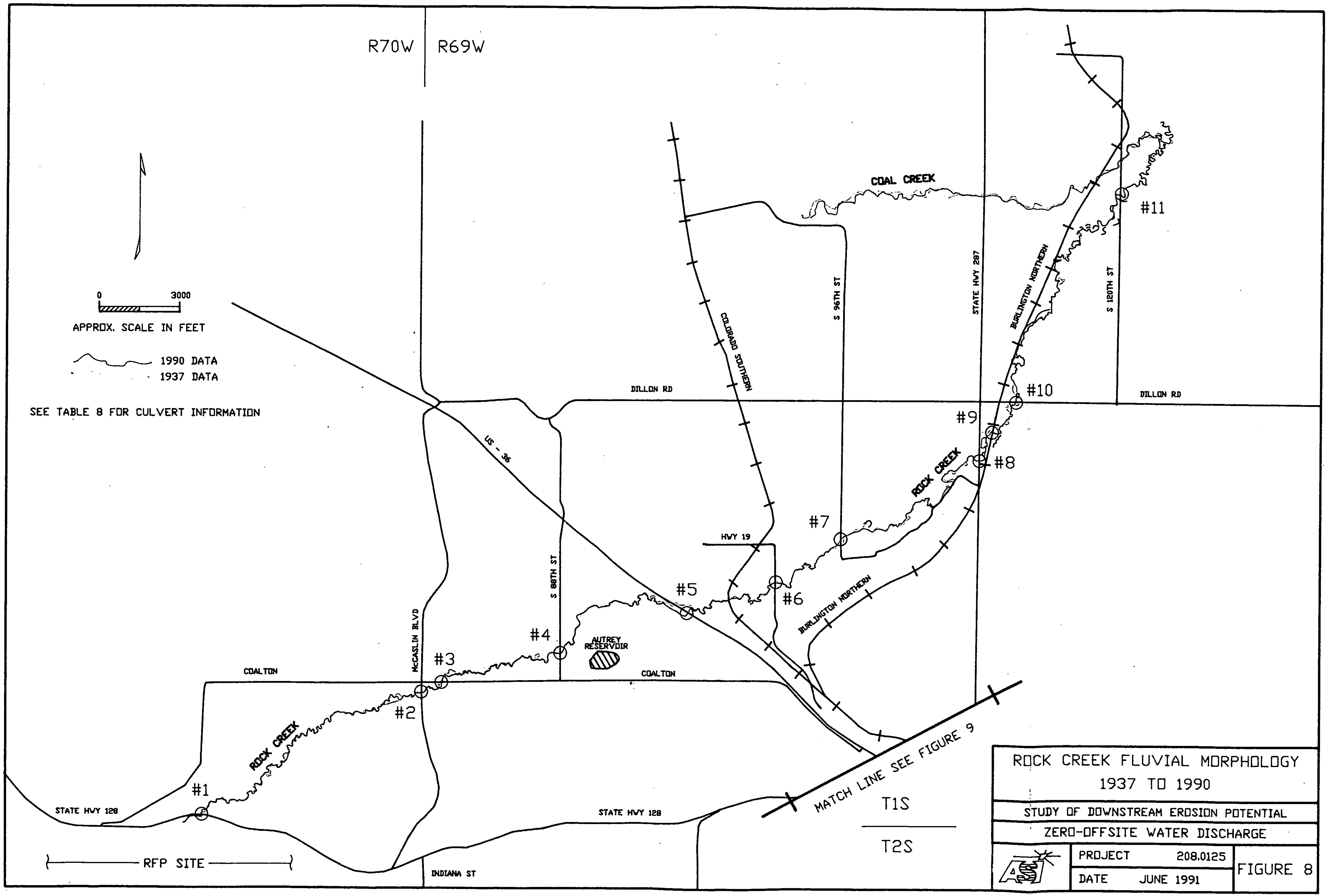
STUDY OF DOWNSTREAM EROSION POTENTIAL

ZERO-OFFSITE WATER-DISCHARGE

PROJECT 208.01.25

DATE JUNE 1991

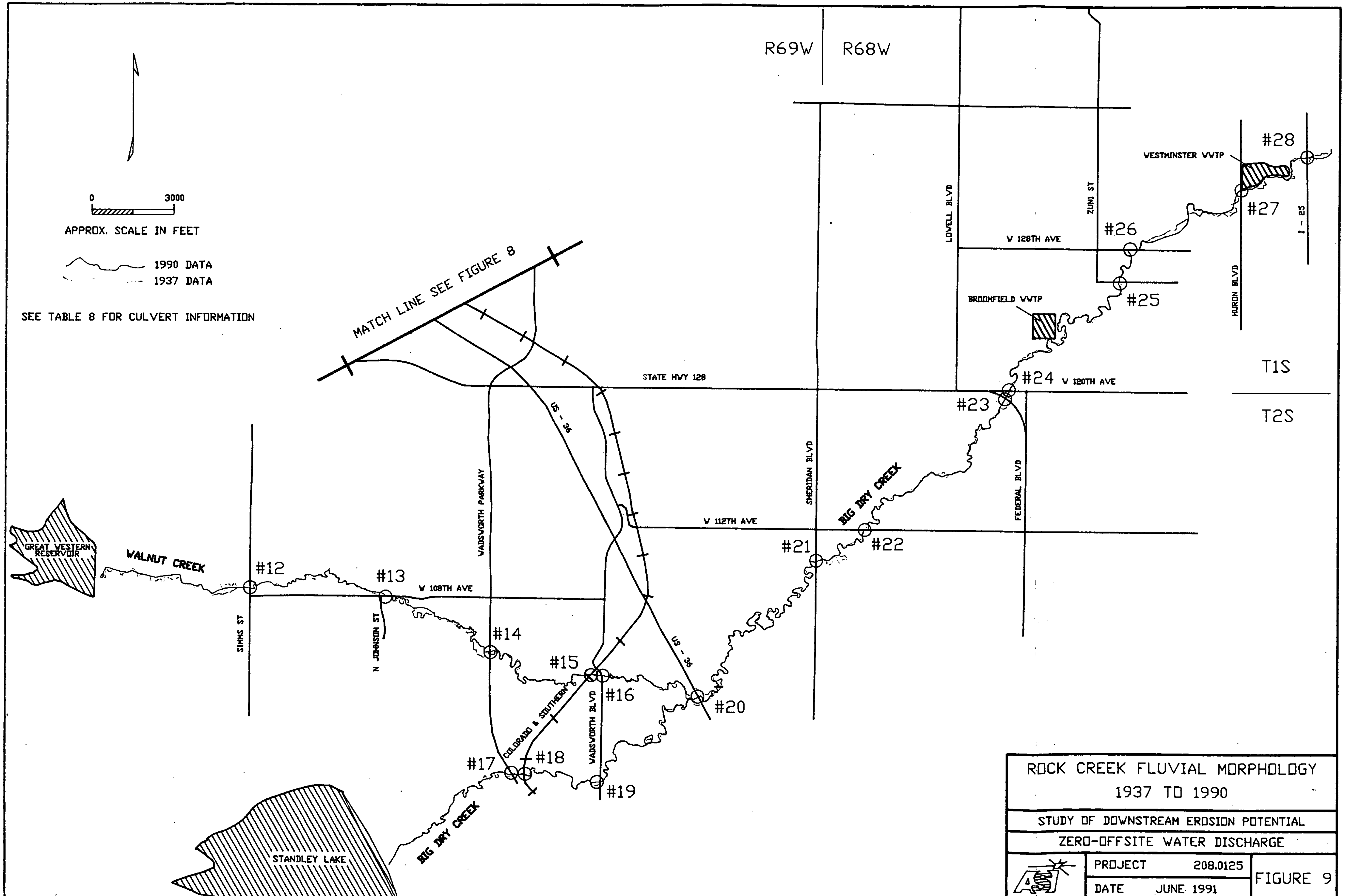
FIGURE 7



ROCK CREEK FLUVIAL MORPHOLOGY
1937 TO 1990

STUDY OF DOWNSTREAM EROSION POTENTIAL
ZERO-OFFSITE WATER DISCHARGE

PROJECT 208.0125
DATE JUNE 1991
FIGURE 8



ROCK CREEK FLUVIAL MORPHOLOGY
1937 TO 1990

STUDY OF DOWNSTREAM EROSION POTENTIAL
ZERO-OFFSITE WATER DISCHARGE

PROJECT	208.0125	FIGURE 9
DATE	JUNE 1991	

A

APPENDIX A

STREAM-SECTION VELOCITIES - 100 YEAR FLOOD

Table A-1

Velocity of Walnut Creek - 100 Year Flood

SECNO	DEPTH	VLOB	VCH	VROB
100.00	19.10	.53	.99	.49
700.00	14.88	1.49	2.73	1.06
2520.00	5.79	3.88	7.86	3.71
3670.00	10.22	3.69	6.59	3.18
4890.00	5.62	4.81	8.84	4.47
4930.00	6.06	3.92	7.00	3.75
4970.00	8.55	1.78	3.17	1.97
5010.00	7.36	2.46	4.81	2.78
5050.00	7.44	2.40	4.66	2.71
5250.00	21.44	.39	.69	.52
5330.00	20.54	.42	.81	.56
5850.00	19.05	.72	1.39	1.05
6795.00	10.44	2.07	4.04	2.07
8310.00	4.89	6.43	10.20	8.30
9050.00	7.73	5.20	9.31	4.43
10450.00	7.62	4.71	11.96	4.67
11870.00	8.83	2.69	8.78	4.11
11900.00	9.12	2.37	7.58	3.60
12010.00	9.74	3.16	10.06	4.10
12040.00	10.74	1.42	1.96	1.40
12600.00	8.47	5.17	10.11	5.66
13410.00	6.69	.00	8.24	.00
14320.00	4.73	5.76	6.95	5.74
15120.00	5.77	2.85	6.58	2.67
15900.00	4.79	5.41	7.79	3.99
15950.00	6.70	2.51	3.50	2.14
16090.00	13.54	.60	1.09	.88
16140.00	12.95	.66	1.07	.95
17000.00	10.89	1.68	2.26	1.49
18550.00	6.15	8.06	10.19	5.10
20100.00	8.90	5.17	9.07	2.31
21100.00	6.59	3.70	8.82	4.05
22050.00	5.83	4.10	8.75	5.20
23460.00	6.38	3.16	9.06	3.14
24850.00	6.99	4.38	10.26	5.75

Table A-2

Velocity of Big Dry Creek - 100 Year Flood

SECNO	DEPTH	VLOB	VCH	VROB
.00	9.96	6.78	11.82	4.27
400.00	11.43	4.24	7.71	3.17
440.00	10.78	.00	16.21	.00
545.00	16.67	.00	9.32	.00
600.00	18.40	1.17	2.25	1.05
1090.00	15.84	1.27	2.49	1.22
1980.00	13.41	.99	1.86	.91
2790.00	15.08	1.25	2.78	1.38
3210.00	12.52	1.63	6.37	3.22
3590.00	12.89	2.72	11.55	3.75
3740.00	13.92	4.56	10.19	3.07
3880.00	13.19	3.28	7.45	2.37
4000.00	13.50	3.09	7.64	2.79
4020.00	13.01	3.87	5.64	2.98
4080.00	13.01	3.87	5.63	2.97
4100.00	13.27	1.04	2.30	1.17
4840.00	11.88	2.21	6.28	3.46
5580.00	12.19	3.63	10.23	4.25
6170.00	13.06	3.09	7.63	2.94
6550.00	11.91	4.29	11.69	3.86
6570.00	7.88	1.00	2.07	2.38
6650.00	6.94	.87	2.18	2.95
6990.00	7.04	2.49	4.84	3.50
8035.00	5.99	2.92	6.14	3.23
8910.00	6.72	2.04	3.94	2.26
8940.00	8.71	.00	14.58	.00
8980.00	8.95	.00	14.06	.00
9010.00	13.03	.68	1.37	.75
10100.00	12.61	2.27	5.13	2.36
11160.00	13.09	1.94	6.00	3.05
11260.00	13.20	3.83	12.82	4.59
11284.00	13.40	3.67	12.04	4.37
11310.00	14.65	1.96	5.51	2.59
12270.00	13.63	1.96	7.53	3.59
14070.00	14.43	2.31	7.54	2.90
15960.00	13.49	5.41	10.25	3.31
17970.00	14.02	2.29	7.16	1.48
19680.00	13.90	3.33	11.13	3.72
20615.00	15.14	4.06	12.20	3.38
21880.00	15.67	2.20	5.62	1.52
21915.00	16.30	2.62	10.63	2.82
21945.00	16.48	2.55	9.92	2.75

Table A-2 - Continued

Velocity of Big Dry Creek - 100 Year Flood

SECNO	DEPTH	VLOB	VCH	VROB
22070.00	16.66	1.71	4.64	1.25
22140.00	16.70	1.70	4.61	1.24
22215.00	17.51	.26	6.88	.86
22250.00	18.45	1.15	3.05	1.21
23100.00	18.29	1.26	5.18	1.48
24300.00	16.53	.00	2.96	.82
25400.00	13.47	1.15	8.30	1.90
26200.00	13.94	2.64	5.64	2.85
26720.00	13.37	2.43	6.91	3.65
26930.00	12.32	5.05	17.06	5.96
27300.00	5.48	3.56	10.75	.00
28170.00	9.54	3.20	6.46	2.74
28965.00	10.97	3.59	8.33	2.75
29650.00	12.04	2.29	11.09	.33
30540.00	14.20	3.40	7.92	2.25
31380.00	13.68	3.12	8.53	2.34
33000.00	13.27	.26	5.28	1.81
33040.00	16.55	3.58	11.30	3.65
33070.00	16.59	3.57	11.17	3.63
33100.00	17.91	1.20	3.20	1.18
33800.00	15.34	1.07	3.31	.95
34200.00	14.10	1.98	5.00	.37
35100.00	12.19	.00	5.20	2.70
35740.00	13.75	2.80	13.26	3.83
35820.00	15.88	2.63	9.13	3.40
35880.00	23.85	2.24	10.52	2.75
35930.00	25.00	1.12	2.60	.99
37170.00	19.45	.66	1.52	.85
37910.00	18.35	2.15	7.59	1.61
39450.00	14.28	1.12	3.60	2.23
40050.00	14.10	1.15	3.16	.90
42760.00	12.22	2.48	11.03	.00
47240.00	14.00	.96	4.78	1.23
49240.00	11.21	1.47	6.11	2.35
51480.00	9.50	3.00	7.21	2.19
51580.00	9.04	.00	11.07	.00
51700.00	23.10	.00	9.12	.00
51770.00	22.80	.60	1.25	.68
52700.00	17.32	.41	1.14	.51
53000.00	16.02	.71	1.77	.51
54000.00	12.03	1.24	3.45	.84

Table A-2 - Continued

Velocity of Big Dry Creek - 100 Year Flood

SECNO	DEPTH	VLOB	VCH	VROB
55540.00	7.84	1.86	6.08	1.82
57550.00	5.47	2.84	9.93	4.03
59560.00	6.09	2.13	5.33	1.87
59600.00	6.07	2.16	5.40	1.89
59630.00	9.48	2.05	5.92	.00
59690.00	9.73	.70	1.69	1.00
61400.00	8.04	2.12	8.94	2.47
63660.00	6.58	2.29	7.42	.77
63760.00	5.94	.00	12.25	.00
63860.00	17.80	.00	15.88	.00
63930.00	17.60	.48	.93	.36
64440.00	13.92	.75	2.57	1.01
64560.00	12.94	.86	3.21	1.29
64730.00	12.00	.59	9.82	3.29
64780.00	11.99	1.16	3.83	1.72
65500.00	7.76	2.94	9.45	2.33
66500.00	6.51	.00	6.11	1.77
69840.00	7.13	3.12	6.20	1.62
71400.00	6.34	.57	7.58	.60
72060.00	9.21	.00	4.05	.00
72100.00	4.44	.00	10.52	.00
72190.00	6.19	.00	6.84	.00

B

APPENDIX B

VELOCITY COMPARISONS

Table B-1

Velocity Comparisons

Walnut Creek

Section Numbers	Current Baseflow	Current Baseflow Channel Velocity (ft/s)	Future Baseflow	Future Baseflow Channel Conditions (ft/s)	Change in Channel Velocity (ft/s)
100	10	0.13	13	0.07	-0.06
700	10	1.89	13	3.70	1.81
2520	10	1.13	13	1.06	-0.07
3670	10	1.37	13	1.58	0.21
4890	10	2.91	13	3.02	0.11
4930	10	1.29	13	1.45	0.16
4970	10	0.75	13	0.89	0.14
5010	10	2.58	13	2.79	0.21
5050	10	1.34	13	1.48	0.14
5250	10	1.43	13	1.54	0.11
5330	10	2.26	13	2.23	-0.03
5850	10	1.82	13	2.02	0.20
6795	10	1.86	13	1.98	0.12
8310	10	10.90	13	10.91	0.01
9050	10	9.12	13	9.12	0
10450	10	12.18	13	12.18	0
11870	10	8.68	13	8.68	0
11900	10	7.63	13	7.59	-0.04
12010	10	3.84	13	3.84	0
12040	10	2.19	13	2.19	0
12600	10	10.33	13	10.32	-0.01
13410	10	6.52	13	6.52	0
14320	10	7.68	13	7.67	-0.01
15120	10	6.36	13	6.36	0
15900	10	7.89	13	7.89	0
15950	10	3.54	13	3.54	0
16090	10	1.09	13	1.09	0
16140	10	1.07	13	1.07	0
17000	10	2.56	13	2.56	0
18550	10	10.64	13	10.64	0
20100	10	9.30	13	9.30	0

Table B-1 - Continued

Velocity Comparisons

Walnut Creek

Section Numbers	Current Baseflow	Current Baseflow Channel Velocity (ft/s)	Future Baseflow	Future Baseflow Channel Conditions (ft/s)	Change in Channel Velocity (ft/s)
21100	10	11.70	13	11.70	0
22050	10	9.20	13	9.20	0
23460	10	11.03	13	11.03	0
24850	10	11.80	13	11.80	0

Table B-2

Velocity Comparisons

Big Dry Creek

Section Numbers	Current Baseflow	Current Baseflow Channel Velocity (ft/s)	Future Baseflow	Future Baseflow Channel Conditions (ft/s)	Change in Channel Velocity (ft/s)
0	20	3.34	26	2.38	-0.96
400	20	1.26	26	1.37	0.11
440	20	1.06	26	1.20	0.14
545	20	1.06	26	1.20	0.14
600	20	1.28	26	1.45	0.17
1090	20	2.46	26	2.16	-0.30
1980	20	1.20	26	1.36	0.16
2790	20	0.48	26	0.58	0.10
3210	20	4.32	26	4.62	0.30
3590	20	1.03	26	1.13	0.10
3740	20	1.75	26	1.86	0.11
3880	20	2.42	26	2.60	0.18
4000	20	1.27	26	1.45	0.18
4020	20	5.64	26	5.87	0.23
4080	20	2.46	26	2.68	0.22
4100	20	0.25	26	0.29	0.04
4840	20	1.38	26	1.48	0.10
5580	20	1.84	26	1.98	0.14
6170	20	2.23	26	2.39	0.16
6550	20	4.72	26	4.28	-0.44
6570	20	0.00	26	0.00	0.00
6650	20	0.00	26	0.00	0.00
6990	20	0.00	26	0.00	0.00
8035	20	1.23	26	1.36	0.13
8910	20	0.39	26	0.42	0.03
8940	20	1.12	26	1.30	0.18
8980	20	1.12	26	1.30	0.18
9010	20	1.00	26	1.17	0.17
10100	20	0.61	26	0.67	0.06
11160	20	0.71	26	0.79	0.08
11260	20	2.03	26	2.10	0.07

Table B-2 - Continued

Velocity Comparisons

Big Dry Creek

Section Numbers	Current Baseflow	Current Baseflow Channel Velocity (ft/s)	Future Baseflow	Future Baseflow Channel Conditions (ft/s)	Change in Channel Velocity (ft/s)
11284	20	1.63	26	1.77	0.14
11310	20	0.62	26	0.72	0.10
12270	20	1.81	26	1.77	-0.04
14070	20	0.81	26	0.90	0.09
15960	20	1.48	26	1.62	0.14
17970	20	1.00	26	1.10	0.10
19680	20	1.25	26	1.38	0.13
20615	20	1.53	26	1.69	0.16
21880	20	1.30	26	1.42	0.12
21915	20	1.97	26	2.02	0.05
21945	20	1.42	26	1.53	0.11
22070	20	1.97	26	2.13	0.16
22140	20	1.28	26	1.42	0.14
22215	20	2.66	26	2.29	-0.37
22250	20	0.91	26	1.06	0.15
23100	20	0.96	26	1.07	0.11
24300	20	1.44	26	1.38	-0.06
25400	20	1.37	26	1.64	0.27
26200	20	0.81	26	0.89	0.08
26720	20	1.32	26	1.39	0.07
26930	20	1.26	26	1.41	0.15
27300	20	2.48	26	2.67	0.19
28170	20	0.78	26	0.89	0.11
28965	20	0.69	26	0.77	0.08
29650	20	1.02	26	1.10	0.08
30540	20	1.58	26	1.76	0.18
31380	20	1.12	26	1.22	0.10
33000	20	1.15	26	1.27	0.12
33040	20	2.75	26	2.90	0.15
33070	20	1.41	26	1.62	0.21
33100	20	0.55	26	0.65	0.10
33800	20	2.38	26	2.43	0.05

Table B-2 - Continued

Velocity Comparisons

Big Dry Creek

Section Numbers	Current Baseflow	Current Baseflow Channel Velocity (ft/s)	Future Baseflow	Future Baseflow Channel Conditions (ft/s)	Change in Channel Velocity (ft/s)
34200	20	1.20	26	1.34	0.14
35100	20	1.50	26	1.67	0.17
35740	20	1.02	26	1.14	0.12
35820	20	0.97	26	1.08	0.11
35880	20	0.89	26	1.03	0.14
35930	20	1.23	26	1.37	0.14
37170	20	1.83	26	2.06	0.23
37910	20	1.58	26	1.75	0.17
39450	20	1.42	26	1.54	0.12
40050	20	0.96	26	0.75	-0.21
42760	20	2.55	26	2.51	-0.04
47240	20	1.38	26	1.53	0.15
49240	20	2.00	26	2.14	0.14
51480	20	1.62	26	1.80	0.18
51580	20	1.59	26	1.74	0.15
51700	10	1.47	13	1.44	-0.03
51770	10	2.61	13	3.05	0.44
52700	10	1.25	13	1.31	0.06
53000	10	1.75	13	1.94	0.19
54000	10	1.29	13	1.38	0.09
55540	10	1.23	13	1.37	0.14
57550	10	1.13	13	1.25	0.12
59560	10	1.50	13	1.15	-0.35
59600	10	1.68	13	1.28	-0.40
59630	10	1.05	13	1.01	-0.04
59690	10	0.73	13	0.73	0.00
61400	10	4.22	13	4.49	0.27
63660	10	1.09	13	1.17	0.08
63760	10	2.63	13	2.86	0.23
63860	10	1.04	13	1.18	0.14
63930	10	1.71	13	1.85	0.14
64440	10	1.30	13	1.45	0.15

Table B-2 - Continued

Velocity Comparisons

Big Dry Creek

Section Numbers	Current Baseflow	Current Baseflow Channel Velocity (ft/s)	Future Baseflow	Future Baseflow Channel Conditions (ft/s)	Change in Channel Velocity (ft/s)
64560	10	1.43	13	1.57	0.14
64730	10	1.45	13	1.64	0.19
64780	10	2.58	13	2.70	0.12
65500	10	1.19	13	1.31	0.12
66500	10	1.48	13	1.61	0.13
69840	10	1.39	13	1.50	0.11
71400	10	1.45	13	1.65	0.20
72060	10	0.29	13	0.35	0.06
72100	10	2.46	13	2.66	0.20
72190	10	0.86	13	0.98	0.12